COSEWIC
Assessment and Status Report

on the

Cusk
Brosme brosme

in Canada

ENDANGERED
2012

COSEWIC
Committee on the Status
of Endangered Wildlife
in Canada

COSEPAC
Comité sur la situation
des espèces en péril
au Canada

COSEWIC status reports are working documents used in assigning the status of wildlife species suspected of being at risk. This report may be cited as follows:

COSEWIC. 2012. COSEWIC assessment and status report on the Cusk *Brosme brosme* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. x + 85 pp. (www.registrelep-sararegistry.gc.ca/default_e.cfm).

Previous report(s):

COSEWIC. 2003. COSEWIC assessment and status report on the cusk *Brosme Brosme* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. vi + 30 pp.

Production note:
COSEWIC acknowledges Robert O'Boyle for writing the status report on Cusk (*Brosme brosme*) in Canada, prepared under contract with Environment Canada. This report was overseen and edited by Alan Sinclair, Co-chair of the COSEWIC Marine Fishes Species Specialist Subcommittee.

Supplemental information including:

- Collections Examined (Trawl Surveys)
- Appendix 1. Maturity, length and sex analysis
- Appendix 2. Analyses of biomass index trends in Atlantic Halibut industry survey
- Appendix 3. State Space Bayesian model of Cusk population dynamics implemented using R2Winbugs (adapted from Davies and Jonsen, 2011)

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Également disponible en français sous le titre Évaluation et Rapport de situation du COSEPAC sur le Brosme (*Brosme brosme*) au Canada.

Cover illustration/photo:
Cusk — The illustration of *Brosme brosme* on the front cover is from an original by H.L. Todd with control number P02360. It is provided by the Smithsonian Institution, NMNH, Division of Fishes.

Catalogue No. CW69-14/332-2013E-PDF
ISBN 978-1-100-22143-4

Recycled paper

COSEWIC
Assessment Summary

Assessment Summary – November 2012

Common name
Cusk

Scientific name
Brosme brosme

Status
Endangered

Reason for designation
This species is a large, slow-growing, bottom-living fish that resides in the Gulf of Maine and Scotian Shelf, and which has been declining continuously since 1970. The mature portion of the population has declined by approximately 85% over three generations. There is also strong evidence that its area of occupancy has declined considerably. Average fish size has also declined, consistent with a decline in abundance. Limited management efforts have not been effective in halting the decline.

Occurrence
Atlantic Ocean

Status history
Designated Threatened in May 2003. Status re-examined and designated Endangered in November 2012.

COSEWIC
Executive Summary

Cusk
Brosme brosme

Wildlife Species Description and Significance

The Cusk is the only member of its genus and is one of about 20 species of cod-like (Gadiforme) fishes on the east coast of Canada. The combination of a single barbel and a single dorsal fin is diagnostic and identifies this species.

A recent genetic study of population structure suggests that there is limited adult migration across deep water regions, which in combination with limited inter-site exchange of pelagic eggs and larvae because of site-specific circulatory retention and poor survival during drift phases across deep basins, is hypothesized as reducing gene flow. The Northeast and Northwest Atlantic gene pools of Cusk are different with Cusk in more southern parts of the Northwest Atlantic genetically distinct from Northeast Atlantic populations. There is a discontinuity in Cusk distribution between Canada and West Greenland that likely restricts genetic interchange. These observations support a single designatable unit for Canada.

Distribution

The Cusk is a northern species inhabiting subarctic and boreal shelf waters of the north Atlantic. Its centre of abundance in the western Atlantic is between 41-44°N latitude (Gulf of Maine and southern Scotian Shelf) where its distribution overlaps the international border of Canada and the United States in the Gulf of Maine. It also occurs in the deep waters along the edge of the continental shelf off Newfoundland and Labrador where it is rare. It has not been observed in the southern Gulf of St. Lawrence, and only four fish have been taken from the northern Gulf of St. Lawrence since the late 1970s.

Habitat

Common on hard, rough, and rocky substrates it is seldom taken on bottoms of smooth clean sand. The Cusk prefers relatively warm water of intermediate depths on the Scotian Shelf and Gulf of Maine. It is found at temperatures from 0-14°C on the Scotian Shelf with some preference for 6-10°C. Cusk are seldom found near the shore or at depths less than 20-30 m. It mostly occurs between 150-450 m depth throughout its range although recent survey work has found Cusk as deep as 1185 m along the edge of the continental shelf off Nova Scotia.

Biology

The total length (TL) of 50% maturity for Cusk in Canadian waters is 42 cm that is reached by 4-5 years of age. An aging study is currently underway; preliminary estimates suggest that these ages may be low by 100% (i.e. 50% age of maturity at age 10). The largest Cusk encountered in the commercial sampling dataset was 115 cm while the largest Cusk caught in a Halibut survey was 118 cm. Longevity, L_{∞}, estimates range from 111.4-126.6 cm TL. Generation time is estimated to be 12.1 years although preliminary results from a recent aging study suggest that it could be as high as 21 years.

Spawning on the Scotian Shelf takes place from May - August with peak spawning in late June. No discrete spawning sites have yet been determined although it could occur in water deeper than 200 m. Eggs are pelagic and hatch larvae measuring 4 mm. Larvae remain in the upper water column and settle to the bottom at about 50-60 mm. The location of benthic nursery grounds is unknown but may be on rough bottom in deep water. Demersal juveniles and adults remain strongly associated with the substratum and do not swim up into the water column. They are slow-moving, sedentary and solitary and do not form large aggregations.

Cusk predators include Spiny Dogfish, Winter Skate, Atlantic Cod, Atlantic Halibut, White Hake, Atlantic Monkfish and maybe Grey Seals. Their diet consists of Crustacea, particularly crabs, shrimps and euphausiids, fish and brittlestars. Natural mortality is likely in the order of 0.14, comparable to that of other Gadoids.

Population Sizes and Trends

The trend in Fisheries and Oceans Canada (DFO) and US National Marine Fisheries Service (NMFS) bottom trawl survey indices of mature abundance over the last 3 generations is a continuous decline. These surveys may exhibit hyperdepletion where catch rates decline faster than biomass due to range contraction of the species to areas not fully covered by the survey, and the series may overestimate the rate of decline. A commercial longline catch rate series that covers the last 2 generations also shows a continuous decline. These contrast the trend in abundance of Cusk in a Halibut survey that has been stable since 1999. A model of surplus production dynamics of the population that used all the Canadian abundance indices and allowed for hyperdepletion in the trawl survey index was used to estimate the trend in mature biomass over the past 3 generations. The estimated decline was 85% and there is no indication that the decline has ceased.

Threats and Limiting Factors

Overfishing is the most important threat to Cusk. Directed fishing for Cusk has virtually ceased but the species is still taken as bycatch in fisheries for Atlantic Cod, Haddock, Pollock and Atlantic Halibut. Recent landings of Cusk from these fisheries have been in the order of 500 t annually. Cusk are also bycatch in the Lobster fishery where landings of Cusk are prohibited and all catch is discarded. Recent discards have been in the order of 250 t-300 t annually. Discarded Cusk do not likely survive given the propensity for the stomach to evert when they are brought to the surface.

Protection, Status, and Ranks

The Cusk was assessed by COSEWIC as threatened in 2003. The Governor in Council elected not to list the species under SARA (Canada Gazette July 7 2012).

In Canada, DFO Conservation Harvesting Plans are the primary regulatory tool protecting Cusk. Since 1999, directed fishing for Cusk has not been permitted and a system of quota caps was introduced to control Cusk landings. In 2010/11, quota caps for the DFO Maritimes fleets totalled 656 t. When the landings caps are met all Cusk catch must be discarded and most would not survive.

TECHNICAL SUMMARY

Brosme brosme
Cusk Brosme
Range of Occurrence in Canada: Atlantic Ocean (Scotian Shelf – Gulf of Maine, Northwest Atlantic Ocean)

Demographic Information

Generation time (% age of maturity +1/Natural Mortality)	12.1 yrs (could be as high as 21 years)
Is there an observed continuing decline in number of mature individuals?	Yes
Estimated percent of continuing decline in total number of mature individuals within 2 generations (24 years)	72% decline
Estimated percent reduction in total number of mature individuals over the last 3 generations (36 years)	85% decline
Suspected percent reduction in total number of mature individuals over the next 3 generations.	Forward projections were not carried out
Estimated percent reduction in total number of mature individuals over any 3 generation period, over a time period including both the past and the future.	Forward projections were not carried out
Are the causes of the decline clearly reversible and understood and ceased?	No. Overfishing is the main cause of the decline but it has not ceased nor is it clearly reversible.
Are there extreme fluctuations in number of mature individuals?	No

Extent and Occupancy Information

Estimated extent of occurrence	302,311 km²
Index of area of occupancy (IAO)	3,616 km²
Is the total population severely fragmented?	No
Number of locations. Does not apply	NA
Is there an observed continuing decline in extent of occurrence?	Yes
Is there an observed continuing decline in index of area of occupancy?	Yes
Is there an observed continuing decline in number of populations?	Unknown
Is there an observed continuing decline in number of locations?	NA
Is there an observed continuing decline in area, extent and quality of habitat?	No
Are there extreme fluctuations in number of populations?	No
Are there extreme fluctuations in number of locations?	No
Are there extreme fluctuations in extent of occurrence?	No
Are there extreme fluctuations in index of area of occupancy?	No

Number of Mature Individuals (in each population)

Population	**N Mature Individuals (2002-2010 avg); see note below**
Canadian portion	217,000

Note: these numbers are based on the DFO summer bottom trawl surveys. For reasons outlined in this report, they are considered biased low and are a minimum estimate. The true number is considerably higher.

Quantitative Analysis

Probability of extinction in the wild is at least [20% within 20 years or 5 generations, or 10% within 100 years].	Not done

Threats (actual or imminent, to populations or habitats)

Overfishing as bycatch to Cod, Haddock, Pollock, Halibut and Lobster fisheries

Rescue Effect (immigration from outside Canada)

Status of outside population(s)? US portion of population in similar state to that in Canada	
Is immigration known or possible?	Likely limited due to both limited mobility and poor status in the USA
Would immigrants be adapted to survive in Canada?	Yes
Is there sufficient habitat for immigrants in Canada?	Yes
Is rescue from outside populations likely?	No

Status History

COSEWIC: Designated Threatened in May 2003. Status re-examined and designated Endangered in November 2012.

Status and Reasons for Designation

Status: Endangered	**Alpha-numeric code:** A2b
Reasons for designation: This species is a large, slow-growing, bottom-living fish that resides in the Gulf of Maine and Scotian Shelf, and which has been declining continuously since 1970. The mature portion of the population has declined by approximately 85% over three generations. There is also strong evidence that its area of occupancy has declined considerably. Average fish size has also declined, consistent with a decline in abundance. Limited management efforts have not been effective in halting the decline.	

Applicability of Criteria

Criterion A (Decline in Total Number of Mature Individuals): Meets criteria A2b. Abundance indices appropriate for the species indicate a decline in mature individuals of 85% over the past 3 generations and the decline has not ceased.
Criterion B (Small Distribution Range and Decline or Fluctuation): Does not apply. The population distribution exceeds criteria.
Criterion C (Small and Declining Number of Mature Individuals): Does not apply. The number of mature individuals exceeds criteria
Criterion D (Very Small or Restricted Total Population): Does not apply
Criterion E (Quantitative Analysis): Not done.

PREFACE

COSEWIC last assessed Cusk as Threatened in 2003. In 2006, following an Allowable Harm Assessment conducted by DFO in 2004 and subsequent consultations with the provinces, Aboriginal peoples, stakeholders and the public, the Governor in Council referred the assessment back to COSEWIC for reconsideration of the Threatened designation. The explanation provided was that significant emphasis was placed on DFO bottom trawl survey data, which may have exaggerated the decline of Cusk. In December 2006, COSEWIC reaffirmed the original assessment without reassessing the species, citing an absence of new information that would lead to a change in the status of this species. Thus, the species was once again considered for listing on Schedule 1 of SARA. In 2007, DFO undertook a Recovery Potential Assessment (RPA) in support of the SARA listing process. The Governor in Council elected not to list the species under SARA (Canada Gazette July 7 2012).

Since the 2003 COSEWIC assessment, there have been a number of advances in our understanding of Cusk biology, population dynamics and threats. Regarding Cusk biology, a 2009 genetics study further supports the existence of one designatable unit in Canada. Data collected on Canadian and US surveys have allowed more informed discussion on maturity and aging processes. Notwithstanding this, the results of a new Canadian aging study are still pending, which has limited the scope of the population analysis. Regarding population dynamics, the commercial and survey time series of abundance discussed in the 2003 COSEWIC assessment are updated to 2010. As well, a number of DFO-industry surveys that commenced in the mid- to late 1990s are also considered. Size composition data from these commercial and survey activities are a further addition in this assessment. In the 2007 RPA, a preliminary population model of Cusk population dynamics was developed and this model was updated in this status report. Regarding threats, two bycatch studies have been conducted since the 2003 assessment that significantly increase our understanding of Cusk sources of mortality.

Overall, this report provides a significant update to the 2003 COSEWIC assessment.

COSEWIC HISTORY

The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) was created in 1977 as a result of a recommendation at the Federal-Provincial Wildlife Conference held in 1976. It arose from the need for a single, official, scientifically sound, national listing of wildlife species at risk. In 1978, COSEWIC designated its first species and produced its first list of Canadian species at risk. Species designated at meetings of the full committee are added to the list. On June 5, 2003, the *Species at Risk Act* (SARA) was proclaimed. SARA establishes COSEWIC as an advisory body ensuring that species will continue to be assessed under a rigorous and independent scientific process.

COSEWIC MANDATE

The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) assesses the national status of wild species, subspecies, varieties, or other designatable units that are considered to be at risk in Canada. Designations are made on native species for the following taxonomic groups: mammals, birds, reptiles, amphibians, fishes, arthropods, molluscs, vascular plants, mosses, and lichens.

COSEWIC MEMBERSHIP

COSEWIC comprises members from each provincial and territorial government wildlife agency, four federal entities (Canadian Wildlife Service, Parks Canada Agency, Department of Fisheries and Oceans, and the Federal Biodiversity Information Partnership, chaired by the Canadian Museum of Nature), three non-government science members and the co-chairs of the species specialist subcommittees and the Aboriginal Traditional Knowledge subcommittee. The Committee meets to consider status reports on candidate species.

DEFINITIONS
(2012)

Wildlife Species	A species, subspecies, variety, or geographically or genetically distinct population of animal, plant or other organism, other than a bacterium or virus, that is wild by nature and is either native to Canada or has extended its range into Canada without human intervention and has been present in Canada for at least 50 years.
Extinct (X)	A wildlife species that no longer exists.
Extirpated (XT)	A wildlife species no longer existing in the wild in Canada, but occurring elsewhere.
Endangered (E)	A wildlife species facing imminent extirpation or extinction.
Threatened (T)	A wildlife species likely to become endangered if limiting factors are not reversed.
Special Concern (SC)*	A wildlife species that may become a threatened or an endangered species because of a combination of biological characteristics and identified threats.
Not at Risk (NAR)**	A wildlife species that has been evaluated and found to be not at risk of extinction given the current circumstances.
Data Deficient (DD)***	A category that applies when the available information is insufficient (a) to resolve a species' eligibility for assessment or (b) to permit an assessment of the species' risk of extinction.

* Formerly described as "Vulnerable" from 1990 to 1999, or "Rare" prior to 1990.

** Formerly described as "Not In Any Category", or "No Designation Required."

*** Formerly described as "Indeterminate" from 1994 to 1999 or "ISIBD" (insufficient scientific information on which to base a designation) prior to 1994. Definition of the (DD) category revised in 2006.

Environment Canada / Environnement Canada
Canadian Wildlife Service / Service canadien de la faune

Canada

The Canadian Wildlife Service, Environment Canada, provides full administrative and financial support to the COSEWIC Secretariat.

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WILDLIFE SPECIES DESCRIPTION AND SIGNIFICANCE

Name and Classification

The Cusk, *Brosme brosme*, belongs to the Order Gadiformes, of which species classification has been controversial (Van Guelpen 2011). Cohen (1984) elevated Gadinae, Lotinae and Phycinae to the family level, which was followed by Markle (1989) but not followed by Nelson *et al.* (2004) who kept them as subfamilies. The latter placed Cusk in the subfamily Gadinae while Eschmeyer (2011) places the species in the family Lotidae.

Cusk is a monotypic genus. Common names include cusk, tusk, Brosme (Fr), torsk (No) and menek (Ru) (Scott and Scott 1988).

Morphological Description

Cusk are a slow swimming, relatively robust demersal species with a heavy head and elongate body reaching a maximum total length (TL) of greater than 100 cm (Cohen *et al.* 1990). The longest Cusk reported in the DFO Maritimes Science port sampling database is 115 cm while the longest specimen in the Halibut industry survey is 118 cm. There is one dorsal and one anal fin, both of which are elongate and extend posteriorly to a rounded caudal fin (Scott and Scott 1988, Collette and Klein-MacPhee 2002) (Figure 1).

Figure 1. Cusk (*Brosme brosme*) (from COSEWIC 2003).

The combination of a single barbel on the underside of the chin in addition to the single dorsal fin is diagnostic and identifies this species as *Brosme brosme*. The relationship of the anal and dorsal fins with the caudal fin is also distinctive. The dorsal and the anal fins are continuous with the caudal fin at the base but are separated from it by distinct notches (Scott and Scott 1988, Collette and Klein-MacPhee 2002). The small pelvic fins have 4-5 rays and are located below the rounded and brush-like pectoral fins. All fins are thick and fleshy at the base (Collette and Klein-MacPhee 2002). Individual rays are only evident at the margins. The body contains minute, deeply embedded scales (Wheeler 1969). Colour is variously described, being light grey with a brownish tint, paler on the sides, changing to greyish white on the belly in the northeast Atlantic to dark reddish or greenish brown, sometimes lighter brown, shading to cream or white on the belly in the northwest Atlantic (Bigelow and Schroeder 1953, Scott and Scott 1988, Collette and Klein-MacPhee 2002).

Population Spatial Structure and Variability

Cusk are a demersal fish spread widely throughout the North Atlantic. Based upon observations from egg and larval surveys, spawning appears to be widespread and the species does not appear to form spawning aggregations. Given that Cusk from different spawning grounds are reported to have different colouration, growth rate, number of vertebrae and fin rays, length distributions and length/weight relationships (Hareide 1988 *in* Knutsen *et al.* 2009), it is likely that spawning, while widespread throughout the distributional range, is also localized. Little is presently known about the migration and dispersal capacity of the species although it appears to be fairly sedentary, suggesting limited seasonal movement (Halliday 2006).

Knutsen *et al.* (2009) undertook an analysis of the genetic structure of Cusk in the North Atlantic. Using a combination of research and commercial vessels, tissue samples were obtained throughout the species' distributional range (Figure 2) and a microsatellite DNA analysis of 7 loci was undertaken. The overall magnitude of genetic differentiation was quite low, with a global F_{ST} of 0.0014. Pairwise F_{ST} estimates between the only Canadian location surveyed and locations in the remainder of the trans-Atlantic range averaged only 0.0042. Spatial genetic variability was only weakly related to geographical distance between study sites or the separation of study sites along the path of major ocean currents. Rather, a significant effect of bathymetry was found. Limited adult migration across bathymetric barriers in combination with limited inter-site exchange of pelagic eggs and larvae due to site-specific circulatory retention, or poor survival during drift phases across deep basins, was hypothesized as reducing gene flow. Furthermore, the scarcity of catch records from the extremely cold waters off Labrador suggests a discontinuity in Cusk distribution in the northwest Atlantic which likely severely restricts genetic interchange between Cusk off West Greenland and from the Grand Banks and further south (Halliday 2006).

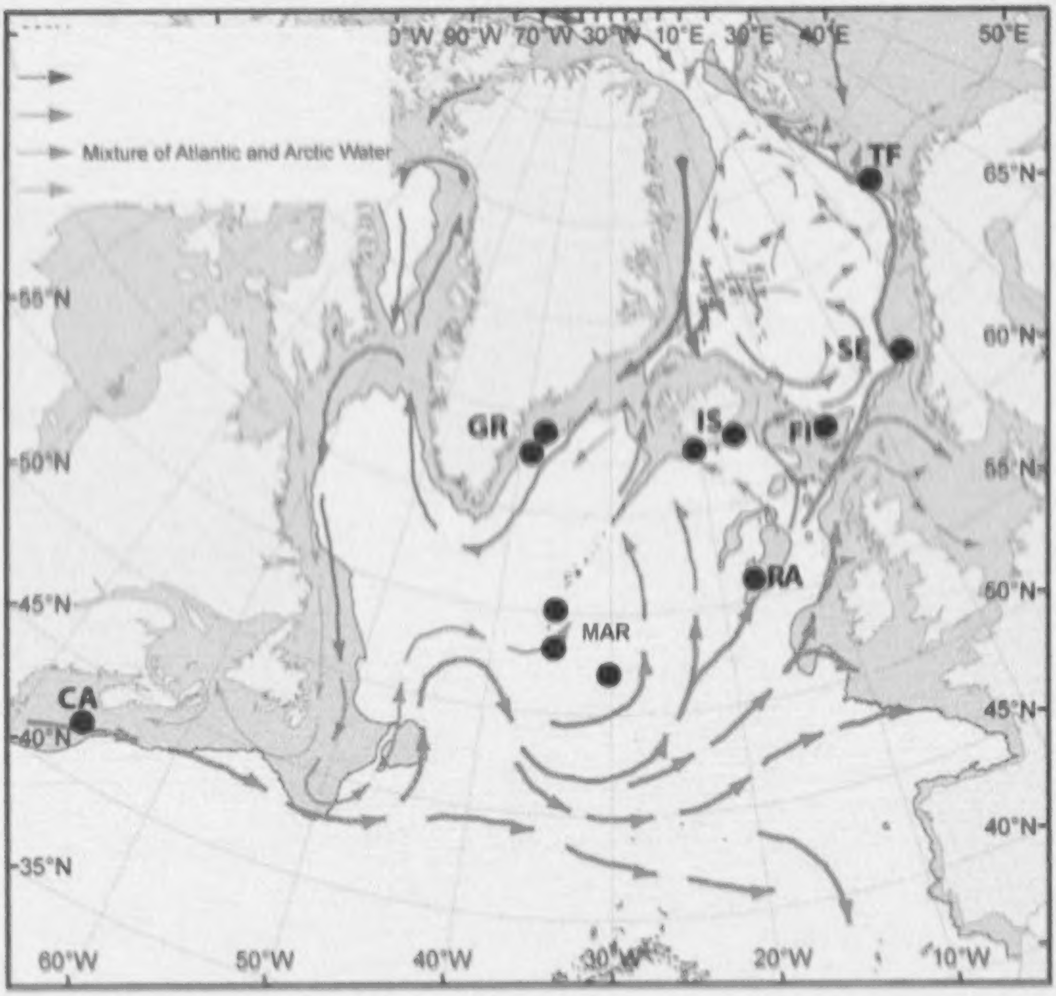

Figure 2. Sample locations of the Knutsen *et al.* (2009) study, together with ocean topography and water masses of the North Atlantic Ocean; Rockall (RA) and Mid-Atlantic Ridge (MAR) are located on sea mountains surrounded by deep areas (white areas >1000 m depth and beyond the maximum depth range of Cusk), Greenland (GR), Iceland (IS), Faroe Island (FI), Storegga (SE) and Tromsøflaket (TF) are interconnected with depth <1000 m (grey shaded areas), and are within the recorded depth range of Cusk (from Knutsen *et al.* 2009).

Designatable Units

Cusk in the North American waters is treated as a single designatable unit (DU) in this report. This is supported by the restricted spatial distribution, with the bulk of the population being located between 41° to 44°N latitude in the Gulf of Maine and southern Scotian Shelf (Figure 3) as well as the studies of barriers to gene flow in Cusk discussed above.

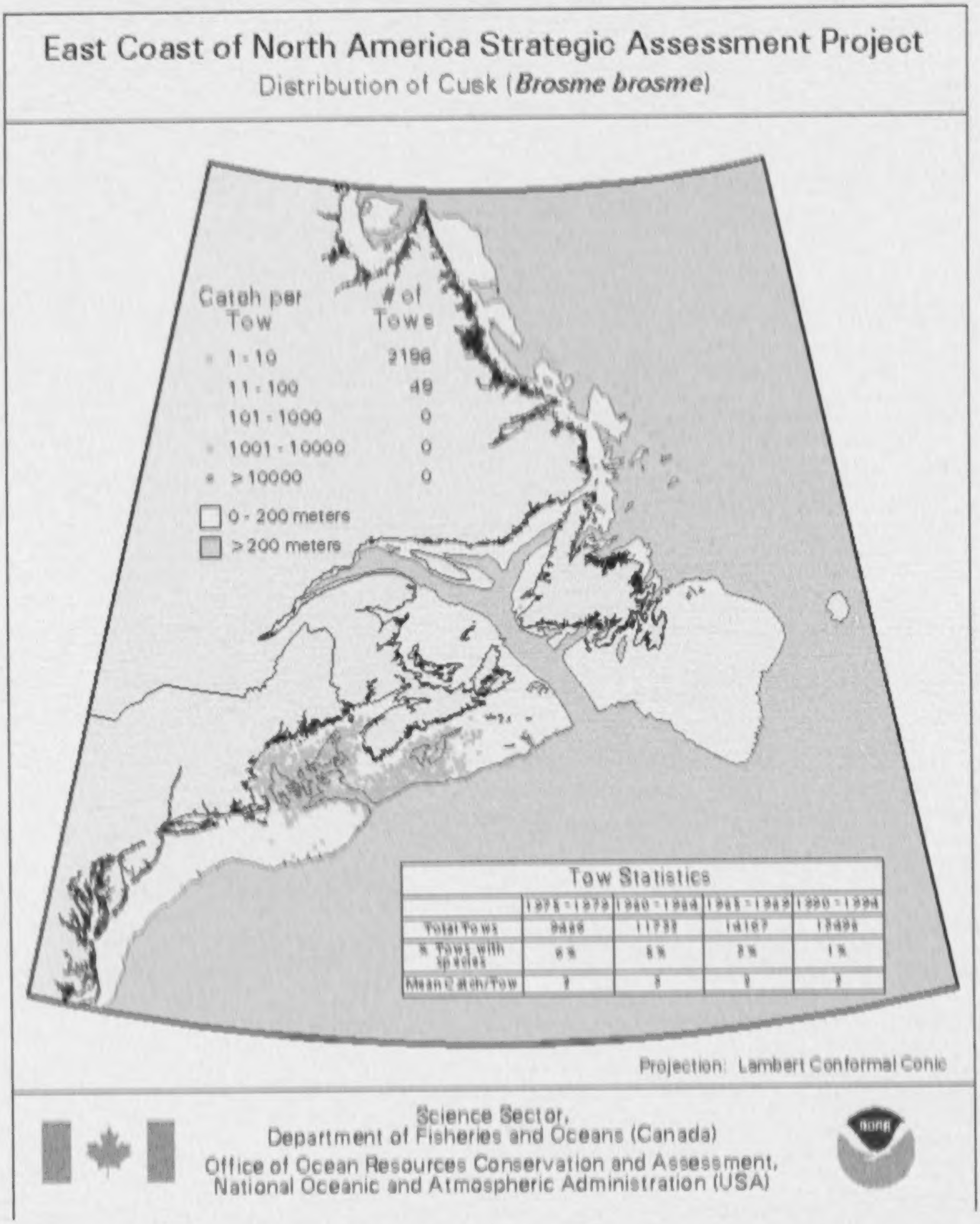

Figure 3. Distribution of Cusk in the Northwest Atlantic (from Brown *et al.* 1996).

The species is transboundary with the US in the Gulf of Maine area. However, given the limited apparent mobility of Cusk, focus in the report is placed upon analysis of Canadian data on the species with examination of US data sources to corroborate observations.

Both the potential discontinuity in Cusk distribution off West Greenland and areas further south (Halliday 2006), and the analyses of and barriers to gene flow in Cusk in the North Atlantic (Knutsen *et al.* 2009), indicate that Cusk in West Greenland may potentially be part of a different population.

Special Significance

Cusk is a monotypic genus. In Canadian east coast waters, it does not have any particular importance as a targeted species but is bycatch in some fisheries (e.g. Cod (*Gadus morhua*), Haddock (*Melanogrammus aeglefinus*), Pollock (*Pollachius virens*), Atlantic Halibut (*Hippoglossus hippoglossus*), and Atlantic Lobster (*Homarus americanus*)). It does not appear to have any socio-economic significance in trade or ceremonial uses.

DISTRIBUTION

Global Range

Cusk are a deepwater demersal fish with a depth distribution that varies within its North Atlantic distribution area, but generally ranges from coastal waters to 1000 m on the upper continental slope, on mid-ocean ridges and in deep fjords (Knutsen *et al.* 2009) (Figure 4.).

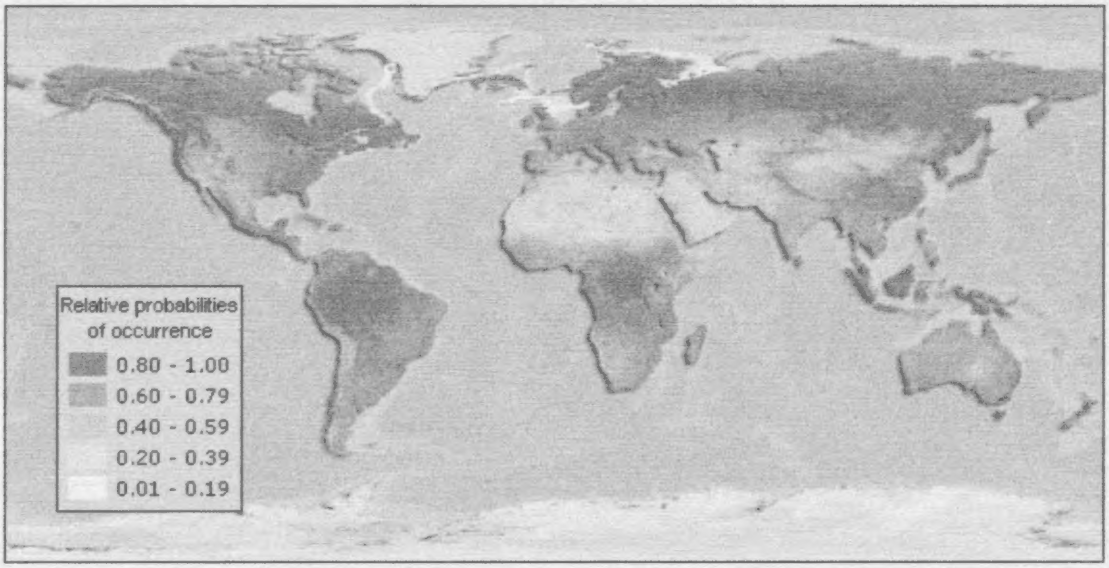

Figure 4. Global distribution of Cusk; relative probability of occurrence is based upon combination of modelled predictions and expert opinion using a variety of data sources (from Harris and Hanke, 2010; see http://en.goldenmap.com/AquaMaps# for details).

In the northwest Atlantic, the species is distributed along the continental shelf from New Jersey to the Strait of Belle Isle, on the Grand Banks of Newfoundland, and off West Greenland. In the northeast Atlantic, it is found off East Greenland, around Iceland and the Faroe Islands and along the European shelf from southern Ireland to the Kola Peninsula and Spitzbergen, including the deeper parts of the North Sea and Barents Sea. Along the Mid-Atlantic Ridge, Cusk occurs south to the Charlie-Gibbs Fracture Zone (Knutsen *et al.* 2009).

Canadian Range

An analysis of Canadian and US East Coast of North America trawl survey data collected during 1975 – 1995 indicated that Cusk belongs to the south-temperate bank/slope assemblage of fishes which ranges from the mid-Atlantic Bight to the Grand Banks off Newfoundland with the centre of distribution being the relatively deep waters of the Gulf of Maine area (Figure 3; Brown *et al.* 1996, Mahon *et al.* 1998). This is a region encompassing about three degrees of latitude extending from approximately 41° to 44° N and covers NAFO divisions 4V, 4W, 4X, 5Y and 5Z (Figure 5). Occurrence of Cusk to the north and south of its core distribution is largely confined to the edge and slope of the continental shelf in relatively deep water. As will be seen in the section on Search Effort, Cusk have not been observed in the Arctic and are rare in the Gulf of St. Lawrence and off Newfoundland. It is evident that Cusk, relative to other members of the Gadidae (e.g. cods, hakes) in the northwestern Atlantic, maintains a very restricted core distribution.

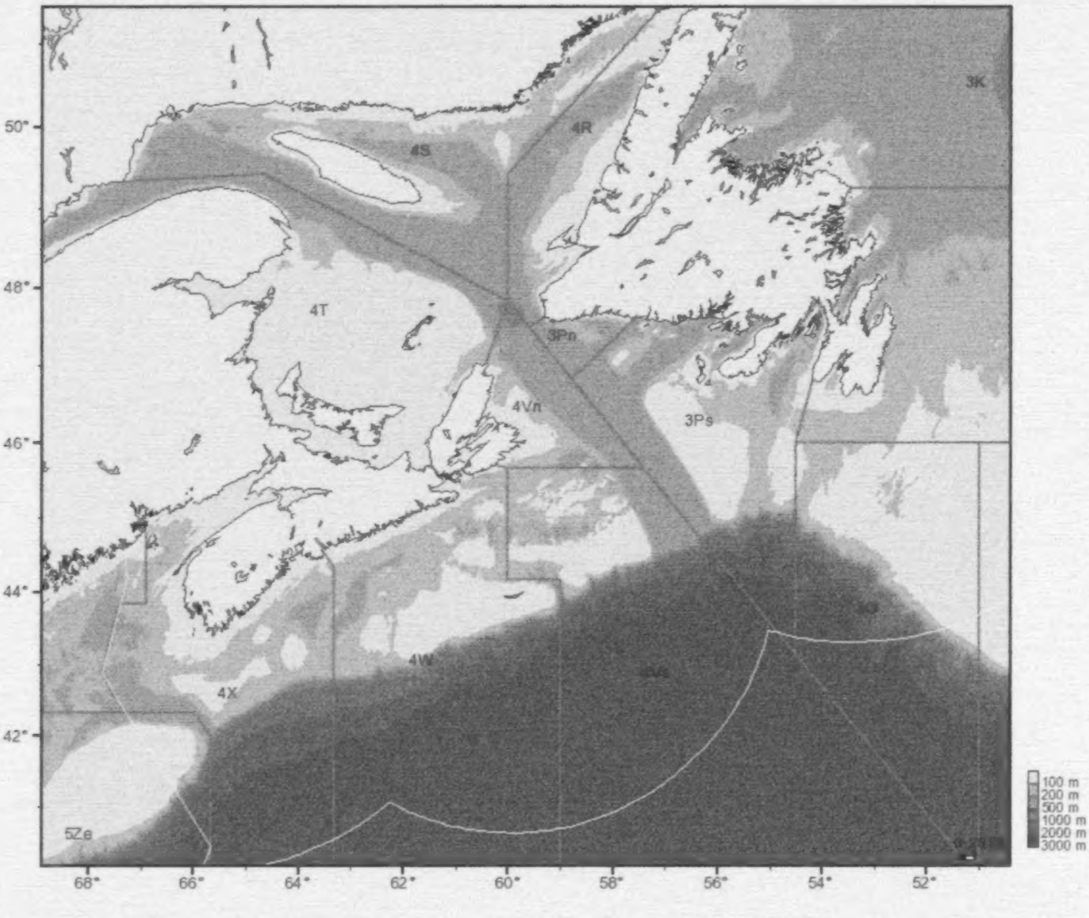

Figure 5. Statistical divisions of the Northwest Atlantic Fisheries Organization (NAFO).

The longest time series of Canadian distributional information is the DFO summer bottom trawl survey on the Scotian Shelf and Bay of Fundy, which has been conducted every July – August since 1970. Concerns have been raised (DFO 2004) that the survey results are not representative of the Cusk population. Other surveys (e.g. Halibut industry) are suggested as being more appropriate (DFO 2008). However, the latter is a relatively short time series with a restricted spatial coverage. It is considered that broad indication on long-term distributional changes can be inferred from the DFO summer bottom trawl survey. However, the results may overestimate the extent of distributional change.

During 1970 – 85, while Cusk ranged the extent of the Scotian Shelf, covering about 172,500 km^2, they were predominantly located off Southwest Nova Scotia (Figure 6). There were also observations along the edge of the continental shelf. By 1995 – 2010, Cusk catches were sparser and more restricted to waters off SW Nova Scotia and in the Gulf of Maine. A similar pattern is evident in the US NMFS fall bottom trawl surveys. During the 1960s-70s, Cusk were abundant throughout the Gulf of Maine while during the 1990s - 2000s, they had become sparser in generally the same area (Figure 7). Cusk are not found on Georges Bank but rather in the Gulf of Maine. As Cusk prefer rocky bottom habitat, it is not surprising that very few are observed on the predominantly sandy bottom Georges Bank.

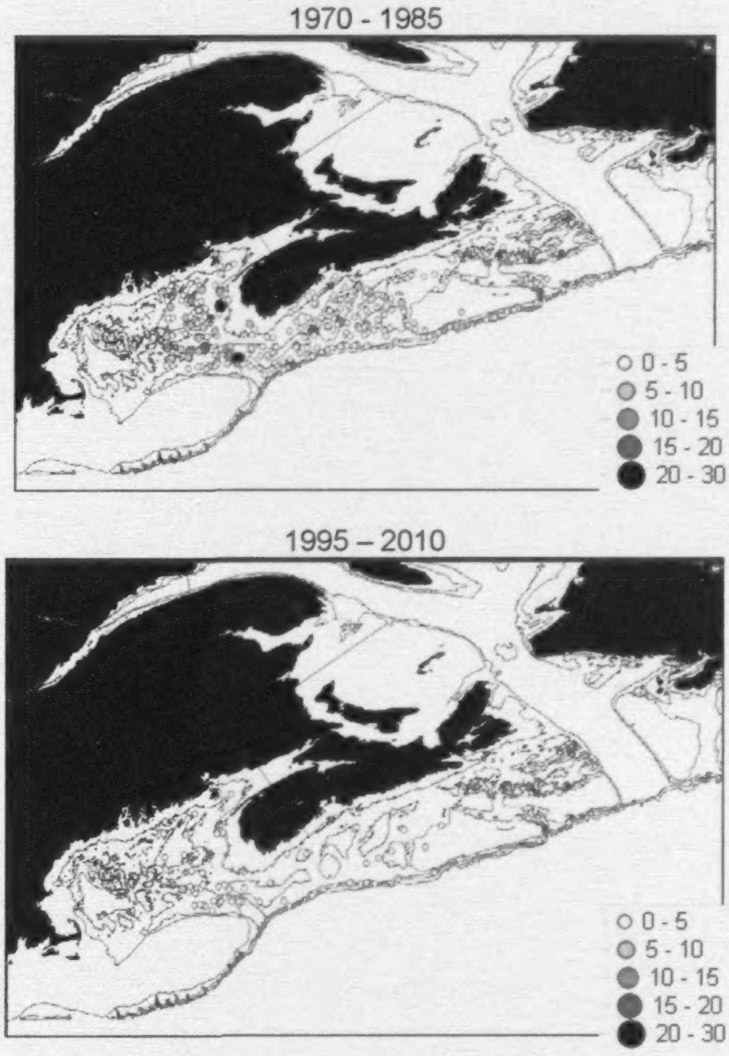

Figure 6. Comparison of Cusk distribution during 1970 – 85 (top panel) to that during 1995 – 2010 (bottom panel) as observed by DFO summer bottom trawl survey; scale is in thousands of individuals.

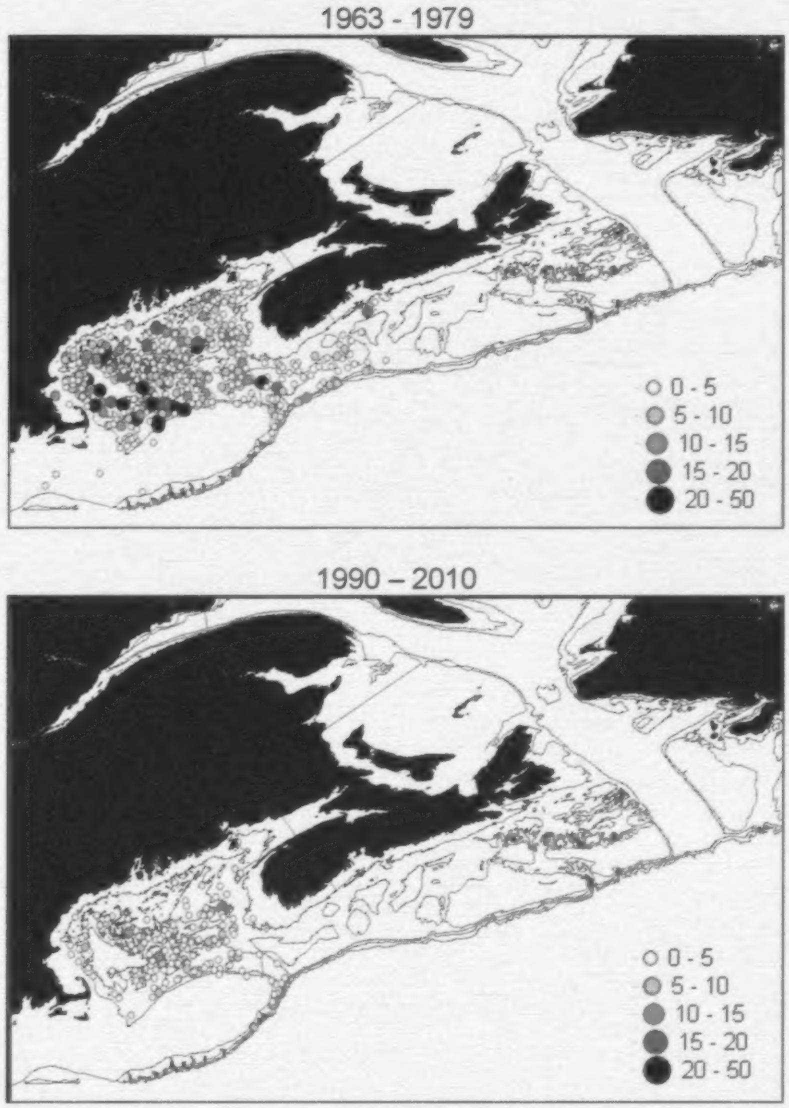

Figure 7. Comparison of Cusk distribution during 1963 - 79 (top panel) to that during 1990 – 2010 (bottom panel) as observed by NMFS fall bottom trawl survey; scale is in kg per tow.

Based on the recent DFO summer bottom trawl survey, the COSEWIC extent of occurrence (EO) is estimated to be 302,311 km^2. The COSEWIC index of the area of occupancy (IAO) was estimated as 3,616 km^2 (based on all life stages) from both the DFO summer and NMFS fall bottom trawl surveys (Wu 2011). Both the EO and IAO have declined in the past 40 years.

DFO Science routinely estimates a design-weighted area index (DWAI) that represents the area occupied by a species (Smedbol *et al.* 2002). It is also expressed as a proportion of the total survey area (NAFO Div. 4VWX). For Cusk, the area and proportion of area occupied have declined considerably from about 40,000 km^2 in the mid-1970s to about 5,000 km^2 more recently (Figure 8).

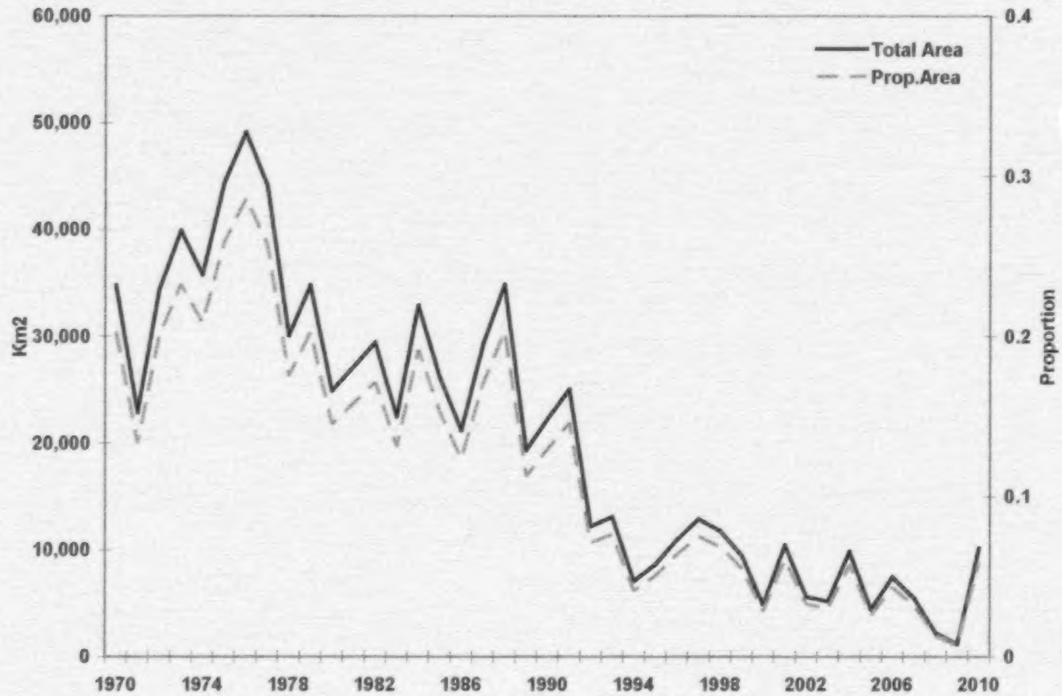

Figure 8. Trend in DFO summer bottom trawl survey area occupied by Cusk; both total (km^2) and proportional area are indicated.

As noted above, the bottom trawl surveys are not considered to representatively sample the Cusk population (DFO 2008). Trends described by the DWAI have been called into question elsewhere (e.g. 4X Cod in Worcester *et al.* 2008). Also, DFO (2008) indicates that since 1998, there has been no trend in the percentage of Halibut Industry survey stations that have caught Cusk and, since 1991, there has been no change in the range of Cusk in the groundfish longline fishery in 4X (Figure 9). DFO (2008) considers that there has been no reduction in the range of Cusk in Canadian waters.

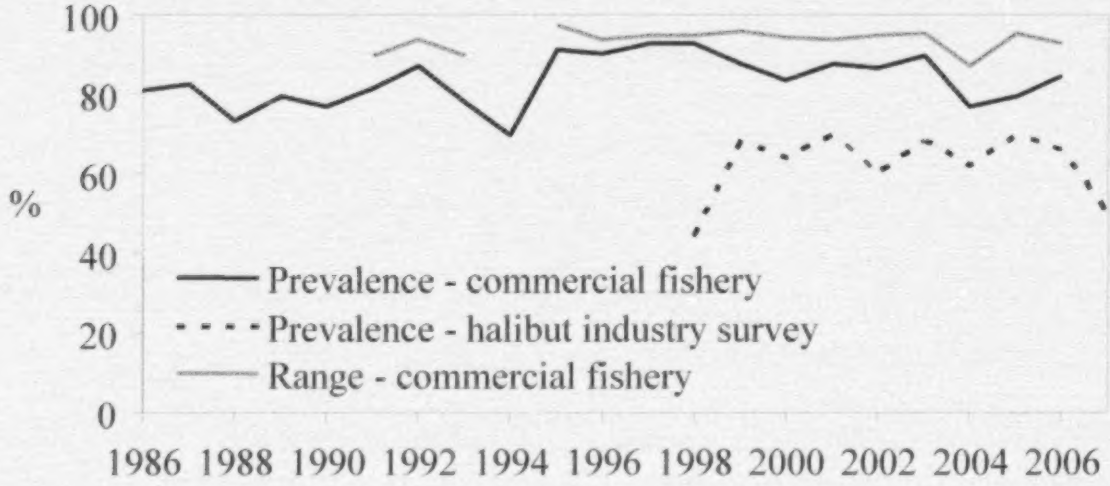

Figure 9. Percentage of commercial groundfish longline trips in 4Xnopq where Cusk were caught (prevalence - commercial fishery), percentage of Halibut industry survey stations which were sampled in all years where Cusk were caught (prevalence - Halibut industry) and percentage of 5 x 5 minute geographic blocks with groundfish longline effort in 4Xnopq where Cusk were caught (range – commercial fishery) (from DFO, 2008).

The magnitude of decline in the DWAI may overestimate the true change in Cusk distribution because the trawl survey is restricted to relatively smooth and sandy bottom types. On the other hand, the commercial fishery and the Halibut survey may be more restricted to the preferred habitat of the species that have remained occupied despite reductions in overall abundance.

Search Effort

A number of surveys have been conducted in the core distributional area (Scotian Shelf – Gulf of Maine) of Cusk. These consist of DFO Maritimes Science spring, summer, fall and winter surveys, NMFS spring, summer, fall and winter surveys and a suite of industry surveys. Elsewhere in the Canadian zone, a variety of bottom trawl surveys have been conducted with similar sampling designs to that of the Scotian Shelf and US surveys (Doubleday 1981). As well, a number of DFO – industry collaborative surveys have also been conducted outside the Cusk core distributional area (Gillis 2002).

Observations of Cusk in all these survey activities have been rare. In the southern Gulf of St. Lawrence, 40 September bottom trawl surveys (1971-2010), six seasonal surveys (1987-1991) and four January surveys (Cabot Strait, 1994-1997) found no Cusk (Morin 2011). In the northern Gulf, there have been no observations of Cusk in the groundfish and shrimp multidisciplinary survey conducted every August since 1984, only two occurrences of Cusk in the RV Gadus Atlantica survey conducted in January during 1978 – 1994 and two occurrences in the October sentinel surveys conducted since 1995 (Bourdages *et al.* 2010, Bourdages 2011). There have been more observations off Newfoundland but even there, Cusk are rare. Of the 95,681 trawl sets in the DFO Newfoundland Science database, which includes all surveys for all seasons and programs since 1947, a total of 254 sets encountered Cusk, most of these having 1 – 2 individuals (Power 2011). There are no reports of Cusk from survey activities in DFO's Central and Arctic Region (Martin 2011, Ratynski 2011, Treble 2011).

The longest time series of consistent observations of Cusk is the summer bottom trawl survey of the Scotian Shelf and Bay of Fundy. It has been conducted every July – August since 1970 using a stratified – random design with standardized data collection and processing protocols (Halliday and Kohler 1971, Doubleday 1981). The survey samples about 50 strata on the Scotian Shelf with an average of 173 trawl sets. Spring and fall bottom trawl surveys covering NAFO Divisions 4VWX5Z in a stratified random design were conducted during 1978/79 – 1984. The Georges Bank February bottom trawl survey has been conducted annually since 1986. Its coverage is restricted to NAFO Subarea 5 with a focus of 5Z. Cusk observations have been limited (Table 1).

Table 1. Number of Cusk observations (individual fish) made on DFO Maritimes Science surveys.

	SPRING	SUMMER	FALL	GEORGES
1970		47		
1971		59		
1972		90		
1973		79		
1974		104		
1975		89		
1976		76		
1977		105		
1978		71	8	
1979	44	81	49	
1980	41	30	63	
1981	54	65	74	
1982	148	92	78	
1983	91	50	53	
1984	69	69	43	
1985		41		
1986		33		11
1987		89		8
1988		70		7
1989		47		9

	SPRING	SUMMER	FALL	GEORGES
1990		44		5
1991		64		0
1992		33		3
1993		12		1
1994		15		0
1995		12		1
1996		14		1
1997		22		1
1998		15		2
1999		10		3
2000		17		2
2001		18		3
2002		14		1
2003		8		1
2004		9		2
2005		38		11
2006		22		3
2007		14		2
2008		9		1
2009		1		0
2010		12		0

The NMFS spring and fall bottom trawl surveys are conducted using a stratified random design with standardized protocol (Grosslein 1974), sampling about 76 strata in the Gulf of Maine area (Table 2). The proportion of sets in the fall survey on which Cusk have been observed has declined over the length of the time series (Figure 10).

Table 2. Number of Cusk observations (individual fish) made on NMFS Science surveys.

	SPRING	SUMMER	FALL	WINTER
1963		38	55	
1964			21	56
1965		61	50	51
1966			78	49
1967			22	
1968	40		42	
1969	49	57	38	
1970	60		60	
1971	50		47	
1972	60		80	10
1973	75		69	
1974	83		33	
1975	42		328	
1976	77		15	

	SPRING	SUMMER	FALL	WINTER
1977	59	29	81	
1978	66	26	115	7
1979	74	18	77	
1980	52	35	67	
1981	102	6	38	
1982	46		10	
1983	30		23	
1984	15		33	
1985	45		48	
1986	59		45	
1987	35		21	
1988	35		34	
1989	32		17	
1990	23		14	
1991	25	2	18	
1992	26		8	
1993	31	21	13	
1994	13	7	12	
1995	8	3	10	
1996	8		15	
1997	9		17	
1998	12		5	2
1999	6		15	1
2000	8		6	
2001	5		19	6
2002	19		12	
2003	27		10	
2004	12		14	
2005	15		12	
2006	11		7	
2007	9		2	
2008	2		13	
2009	27		7	
2010	22		22	
2011	19			

Figure 10. Percent of NMFS fall bottom trawl survey sets that caught Cusk.

A number of DFO deepwater surveys have also been conducted on the Scotian Slope. Observations of Cusk in these surveys have been rare. Ten were caught in a deepwater survey conducted in 360 – 600m depth of water off the Scotian Shelf in 1984 (Markle *et al.* 1988). None were caught in a 1994 trawl survey of 900 – 1800m depth water, a 1991 fixed gear survey of 500 – 2800m depth water as well as a number of mesopelagic surveys conducted in the 1980s (Halliday 2011).

Since 1994, a number of DFO – fishing industry collaborative surveys have been conducted in the Scotian Shelf – Gulf of Maine area (Table 3). Of these, the only surveys that have caught Cusk to any degree are the 4VsW sentinel and Atlantic Halibut surveys. Both of these surveys use longline gear and have been relatively more successful than the DFO and NMFS bottom trawl surveys in catching Cusk. The protocol of the Halibut survey is discussed by Trzcinski *et al.* (2011) while that of the 4VsW sentinel survey is discussed in O'Boyle *et al.* (1995). Sampling intensity in these surveys has however been more limited than the DFO surveys, both in station number (Table 4) and spatial extent (Figure 11). For instance, while the 4VsW sentinel survey covered an extensive part of the Eastern Scotian Shelf prior to 2004 (using the same stratified – random design as the DFO summer bottom trawl survey), station intensity was reduced from about 200 to 53 stations in 2004. Sampling is now concentrated in the Emerald / Western Bank area and along the coast of Nova Scotia both marginal to the overall Cusk distribution. Station coverage by the Halibut survey has been more consistent and is focused on specific fixed stations (Figure 11b). Note that only the most consistently sampled fixed stations (which are in 4VWX) are displayed as these are used to develop the abundance index. Harris and Hanke (2010) consider that a significant feature of the Halibut survey is that it fishes in deepwater areas along the Shelf Break that are not well sampled by the DFO summer trawl survey (see comparison of station locations of two surveys in Figure 11b). Harris and Hanke (2010) indicate that the majority of the Halibut survey Cusk catches are in the deep water along the edge of the Scotian Shelf.

Table 3. Summary of key features of industry surveys conducted in Scotian Shelf – Gulf of Maine area.

	4Vn Sentinel	4VsW Sentinel	Skate	Monkfish
Area	4Vn	4VsW	4VSW	4X
Design	Stratified Random	Stratified Random	Stratified Random	Fixed
Duration	1994 - Present	1995 - present	1994 - 2005	1995 - 1999
Months	June - September	March - October	April - October	September
Gear	No. 12 Circle Hook	No. 12 Circle Hook	Ballon Trawl	Flounder Trawl
No Sets	60	53 - 238	48	141
Cusk weighed	Yes	Yes	Yes	Yes
Cusk Measured	Yes	Yes	Yes	Yes

	ITQ	Georges Bank Groundfish	Atlantic Halibut
Area	4X	5Zc	3NOPs4VWX5Zc
Design	Fixed	Fixed	Fixed
Duration	1995 - present	1995	1998 - present
Months	July	August	Late May - Late July
Gear	Ballon Trawl	No. 12 Circle Hook	No. circle 14 or greater
No Sets	139	31	52 - 62 core
Cusk weighed	Yes	Yes	Yes
Cusk Measured	Yes	No	Not consistently

Table 4. Number of fixed stations sampled during 4VsW Sentinel and Atlantic Halibut surveys.

	4VsW Sentinel	Halibut
1995	221	
1996	237	
1997	233	
1998	237	60
1999	238	57
2000	236	52
2001	187	53
2002	176	52
2003	187	54
2004	53	52
2005	53	54
2006	53	61
2007	53	62
2008	53	54
2009	53	52
2010	64	53
2011		47

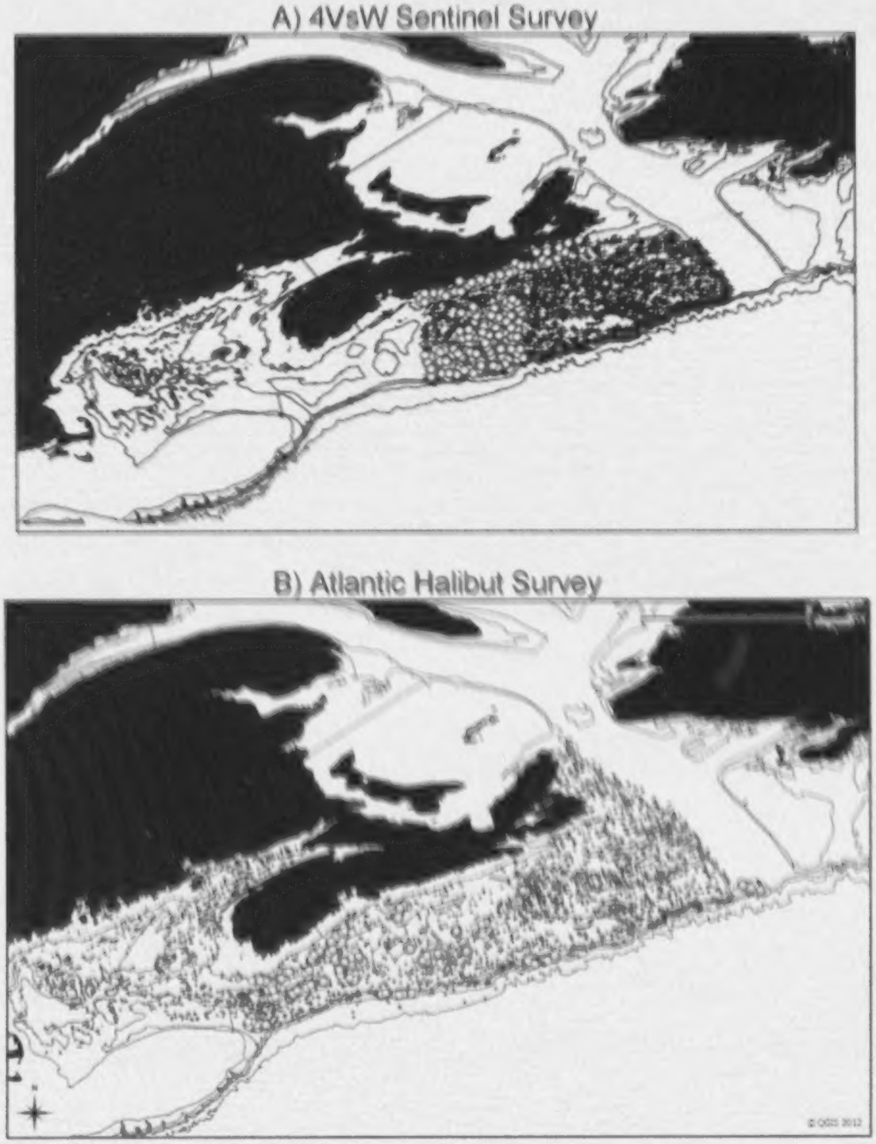

Figure 11. Station distribution of 4VsW sentinel longline survey (a: top panel; + indicates pre-2004 stations and circle indicates post-2003 stations) and Atlantic Halibut industry longline survey (b: bottom panel; open circles indicate Halibut survey sets and + indicates DFO summer survey sets for 2000 - 2010).

HABITAT

Habitat Requirements

Cusk are commonly taken on hard, rough, and rocky substrates and are described by Bigelow and Schroeder (1953) and Collette and Klein-MacPhee (2002) as being "decidedly fastidious in their choice of bottoms, being found chiefly on hard ground, especially where the sea floor is rough with rocks or boulders; on gravely or pebbly grounds, occasionally on mud with hake (*Urophycis*) but seldom on smooth clean sand". They have been observed hiding in crevices (Hovland and Judd 1988, Freiwald *et al.* 2002, Jones *et al.* 2009). Cusk have been taken with longlines and gillnets off southwestern Norway at depths of 150 to 300 m in coral (*Lophelia pertusa*) habitats (Husebø *et al.* 2002). Fish in coral habitats (Svedevidov 1948) tended to be larger in size than those in non-coral habitats. Cusk were also observed associated with carbonate-cemented slabs, sometimes hiding beneath them in seabed pockmarks and seepages in the central North Sea (Hovland and Judd 1988).

Cusk prefer relatively warm intermediate depths in the western Atlantic. Cusk are found at temperatures from 2-12°C on the Scotian Shelf and *ca.*1-10°C in the Gulf of Maine (Scott 1982, Scott and Scott 1988). The preferred temperature range is *ca.* 6-10°C on the Scotian Shelf (Scott 1982, Scott and Scott 1988). The principal fishing areas are reported to coincide with regions having a minimum bottom temperature of about 4°C (Oldham 1972, Scott 1982, Scott and Scott 1988). In the summer bottom trawl survey, 91% of the sets that caught Cusk were at bottom temperatures above 4°C (Table 5). Of the sets made in this temperature range, 13% had Cusk compared to 2% in sets at lower temperatures.

Table 5. Association between Cusk catch, depth, and bottom temperature on the Scotian Shelf as observed in the DFO summer bottom trawl survey during 1970 – 2010; top panel enumerates total number of sets and bottom panel enumerates only those sets on which Cusk were caught.

	Temperature, C										
Depth, m	**0-2**	**2-4**	**4-6**	**6-8**	**8-10**	**10-12**	**12-14**	**14-16**	**16-18**	**18+**	**Total**
<100	731	865	648	576	393	79	13	1	0	0	3306
100-200	404	444	407	718	605	127	8	0	0	0	2713
200-300	100	92	207	264	304	43	2	0	0	0	1012
300-400	13	5	133	83	43	3	0	0	0	0	280
400-500	8	0	26	7	2	0	0	0	0	0	43
500-600	1	1	26	4	1	0	0	0	0	0	33
>600	22	0	17	2	0	0	0	0	0	0	41
Total	1279	1407	1464	1654	1348	252	23	1	0	0	7428
%	17.2%	18.9%	19.7%	22.3%	18.1%	3.4%	0.3%	0.0%	0.0%	0.0%	

Depth, m	**0-2**	**2-4**	**4-6**	**6-8**	**8-10**	**10-12**	**12-14**	**14-16**	**16-18**	**18+**	**Total**
<100	4	14	21	10	7	0	0	0	0	0	56
100-200	16	8	40	136	128	29	1	0	0	0	358
200-300	8	2	7	80	87	6	1	0	0	0	191
300-400	1	0	7	25	16	0	0	0	0	0	49
400-500	0	0	1	1	0	0	0	0	0	0	2
500-600	0	0	2	0	0	0	0	0	0	0	2
>600	0	0	0	0	0	0	0	0	0	0	0
Total	29	24	78	252	238	35	2	0	0	0	658
%	4.4%	3.6%	11.9%	38.3%	36.2%	5.3%	0.3%	0.0%	0.0%	0.0%	

Cusk are rarely if ever found near the shore or at depths less than 20-30 m (Svedevidov 1948). Regarding Cusk's upper depth limit, Cohen *et al.* (1990) and Hareide and Garnes (2001) indicate a species' depth range of between 20 to 1100 m while Andriyashev (1954) reports that Cusk are rarely found deeper than 400 m. Scott (1982) and Scott and Scott (1988) report that the depth range on the Scotian Shelf is 73-363 m based on DFO trawl survey sampling. Ninety percent of the trawl survey sets that caught Cusk were at depths between 100 – 400 m (Table 5). For the sets conducted in this depth range, 15% produced Cusk in contrast to 2% in the 0 – 100 m range and 3 % at depths above 400 m. Of the 41 sets in waters > 600 m, no Cusk were caught. Harris and Hanke (2010) report that catch rates in the Halibut industry survey peaked between 400 – 600m, with Cusk caught at depths as great as 1185 m (no sets were conducted deeper than this).

Habitat Trends

While the large-scale characteristics of the bottom habitat on the Scotian Shelf and in the Gulf of Maine area have been described (Kostylev and Hannah 2007), except for a small area of southwest Nova Scotia (Todd and Kostylev 2011), this is not at a scale which would be informative to this assessment.

In comparison, there is significant information available on the temporal trends of the physical oceanographic conditions that are summarized in Worcester and Parker (2010). Year to year water temperatures on the Scotian Shelf and in the Gulf of Maine area are among the most variable in the North Atlantic. The western Scotian Shelf (WSS) is generally warmer than the Eastern Scotian Shelf (ESS), as warmer Gulf Stream water enters onto the WSS over the southwest slope between Browns and Western banks; whereas, the ESS is more influenced by the cool, low salinity water from the north entering over Misaine Bank near Cape Breton.

Water temperature during 1987-1993 and 2003-2004 were predominantly colder than normal, while 1973-1985 and 1999-2000 was warmer than normal. Variability in water temperature has been increasing in the past decade.

Salinity measurements have been taken since 1924 at a fixed station near Saint Andrews, NB, adjacent to the entrance of the Bay of Fundy. There was a decrease in salinity from the 1940s to the early 1970s. This was followed by an increase in the mid-1970s and another long-term decline to a time series low in 1996. Salinity subsequently increased to 2002, followed again by a decline (Figure 12). This pattern is consistent with the pattern of salinities measured by the US Northeast Fisheries Science Centre on the continental shelf (Gulf of Maine) since the 1970s.

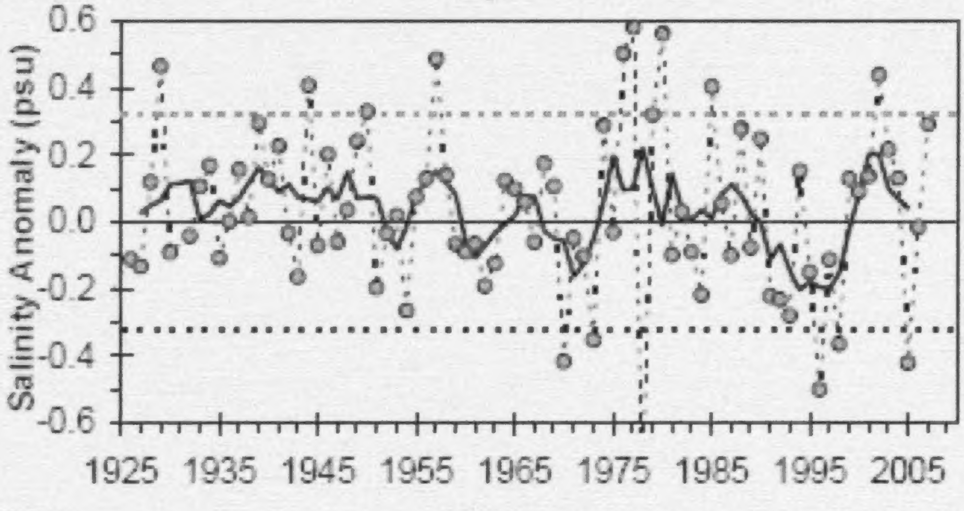

Figure 12. Time series of annual surface salinity anomalies (grey dashed line with dots) and 5-year running means (heavy, black line) (from Worcester *et al.* 2010).

On the Scotian Shelf, the average 0 - 50 m stratification index increased considerably in the 1990s. From the mid- to late 1990s, the index was at or near its maximum over the 50-year record (Figure 13). Stratification in 2008 was above normal by one standard deviation, the 4th strongest in 49 years. Important changes in stratification have also been noted over time in the eastern Gulf of Maine and Georges Bank with increasing temperature and changes in salinity. Stratification has increased steadily from the mid-1980s on Georges Bank and in the eastern Gulf of Maine in a similar manner as on the Scotian Shelf. Strong stratification sometimes inhibits vertical mixing enough to cause dissolved oxygen levels in deeper layers to become depressed. However, although the waters of this ecozone do stratify, low dissolved oxygen has not been apparent with the exception of a few coastal locations and potentially some of the deepest basins.

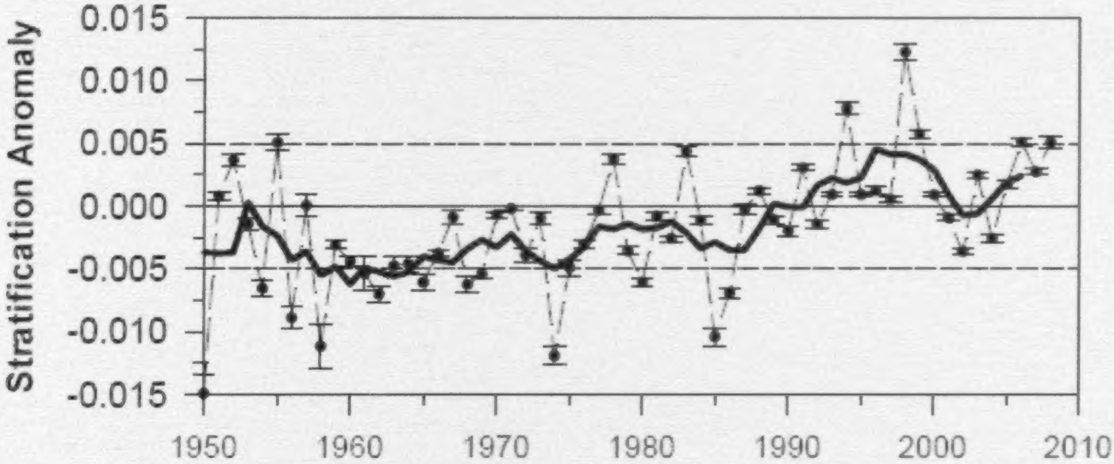

Figure 13. Mean annual (dashed line) and 5-year running mean (solid line) of the stratification index over the Scotian Shelf; anomalies based on 1971-2000 observations; standard error estimates for each annual value are shown (from Worcester *et al.* 2010).

It is difficult to judge from these trends in temperature, salinity, and stratification if Cusk habitat has changed significantly over time. DFO (2008) concluded that habitat does not appear to be, nor is likely to become, a limiting factor to Cusk survival and recovery. It further stated that there are no known threats that have reduced Cusk habitat quantity and quality.

BIOLOGY

Life Cycle and Reproduction

Growth and Maturity

Halliday (2006) reported that the only data on Cusk growth in the Northwest Atlantic are those of Oldham (1972), which indicate that age 5 and 11 Cusk are about 45 cm and 70 cm long respectively. Oldham (1972) calculated that 50% maturity for Cusk in NAFO Div. 4X occurred at age 4.7yr and 43.5 cm for males and at 6.5 yr and 50.7 cm for females. Oldham (1972) also found that males do not grow faster than females although they mature more rapidly. The oldest fish aged was 14.

Maturity at length data collected on the DFO summer and NMFS spring and summer surveys were analyzed using a logistic model to update estimates of the size of maturity. Length and sex were used to explore their relationship with proportion mature. While the DFO data indicated that the interaction between sex and length was significant, the coefficients were similar (*Appendix 1). The NMFS data suggested a stronger sex – length interaction. The DFO and NMFS data indicated that the length at 50% maturity (sexes combined) was about 39 and 42 cm respectively (Figure 14).

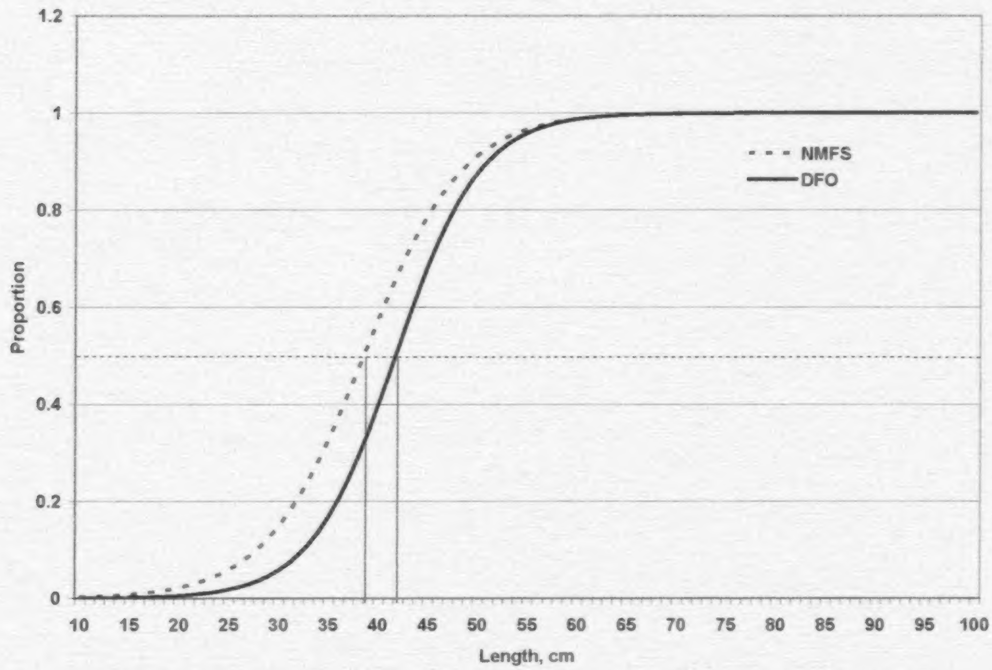

Figure 14. Relationship between Cusk proportion mature (sexes combined) and length (cm) based on an analysis of DFO and NMFS spring – summer surveys.

*Appendix 1. Available upon request by contacting the Secretariat at : cosewic/cosepac@ec.gc.ca

Aging work conducted at the NMFS Northeast Fisheries Science Center (NEFSC) in Woods Hole during 1991 – 95 was made available by O'Brien (2011). Both survey and commercial samples provided 820 otoliths which were used to estimate spring and fall age-length keys. A von Bertalanffy growth model was fit to the data, which provided estimates of L_∞, K and T_0 of 126.56, 0.110 and 0.673 respectively[1]. This growth curve compares reasonably well with the linear model employed by Oldham (1972) (Figure 15). O'Brien (2011) emphasized that these ages have not been validated and are unpublished and thus these data have not been used further in the analysis of Cusk population dynamics in this assessment. This growth curve and the maturity at length relationship described above suggest that 50% maturity occurs between ages 4 and 5, slightly younger than the estimates of Oldham (1972).

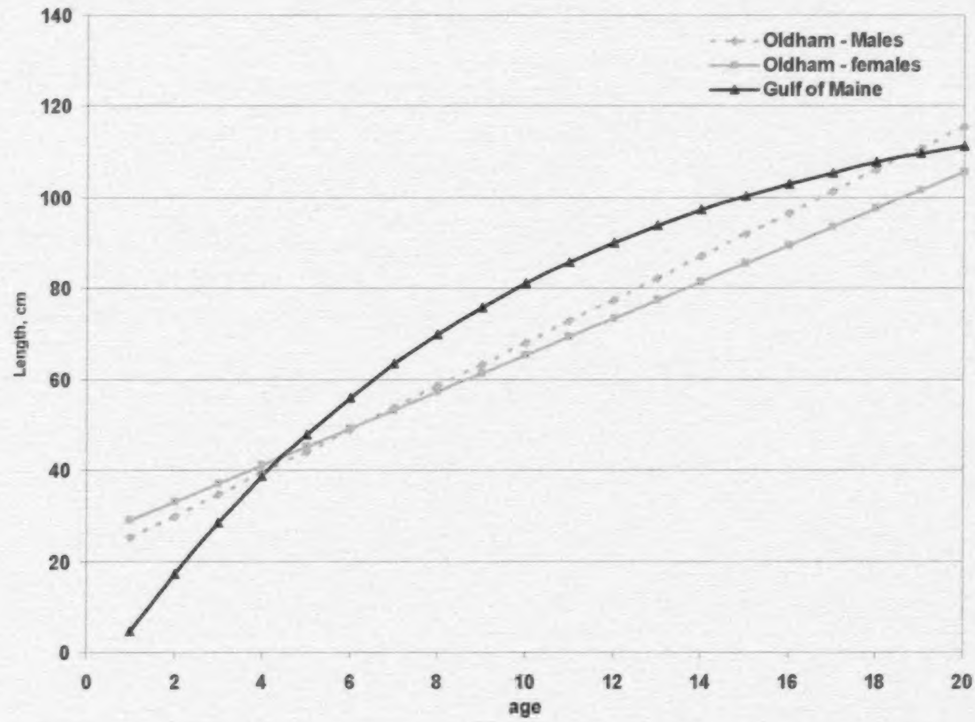

Figure 15. Growth models of Scotian Shelf and Gulf of Maine estimated by Oldham (1972) and O'Brien (2011) respectively.

[1] L_∞, K and T_0 are the maximum length, growth coefficient and time at length of zero for the von Bertalanffy growth model

More recently, radiocarbon bomb dating methods have been used to provide preliminary estimates of the age of Cusk from the Scotian Shelf (Harris and Hanke, 2010). This aging effort has returned older age estimates than the previous Northwest Atlantic studies, including an 82 cm fish aged 39 years. These new data suggest that Cusk may reach maturity by age 10 in contrast to previous estimates of age 4 - 6. These data are currently being further analyzed for publication, which was not available at the time of writing of this report.

In the Northeast Atlantic, Bergstad and Hareide (1996) report lengths at ages 5 and 11 as 35-40 cm and 50-55 cm, respectively. Magnússon *et al.* (1997) give an "average growth" curve showing length at age 5 of about 27cm and at age 11 of about 47cm, substantially lower than Bergstad and Hareide (1996) although largely based on their data (Halliday 2006). Cusk in the Northeast Atlantic reach maturity by 40-45 cm when they are 8 - 10 years of age. No significant difference in growth rate has been observed between the sexes (Magnusson *et al.* 1997). These growth rates are more consistent with the new, preliminary, Northwest Atlantic study than that of Oldham (1972) and O'Brien (2011). Halliday (2006) notes that Cusk are difficult to age (Bergstad *et al.* 1998) and it is possible that the apparent faster growth reported in the northwest Atlantic could, at least in part, be due to differences in interpretation of the otolith rings. The northeast Atlantic age readings were based on intercalibrations among expert age readers from several laboratories and are thought to be more reliable (Halliday 2006). In the northeast Atlantic, ages as old as 20 years have been obtained for Cusk of 70-80 cm. Given that Cusk reach lengths greater than 100 cm, longevity could be substantially greater than that. Icelandic bottom trawl surveys catch many Cusk less that 40 cm with modes at 15 cm that correspond to age 2 fish, and 7 – 8 cm that correspond to age one (Bergstad *et al.* 1998).

Based upon the examination of life history data of over 1200 fish species in FishBase, Froese and Binohlan (2000) provide a relationship between L_∞ and the maximum observed age, L_{MAX} (equation 1), which for Cusk is 115 cm. This provides an estimate of 111.4 cm for L_∞.

$$\mathrm{Ln}(L_\infty) = 0.044 + 0.9841 * \mathrm{Ln}(L_{MAX}) \qquad (1)$$

A rearrangement of the von Bertalanffy growth equation (equation 2), along with estimates of L_∞, L_M (length of maturity of 42 cm) and T_M (age of maturity of either 5 or 10 years) and assuming T_0 is about 0.7 (based on NMFS growth model and age data), estimates of K, the Brody growth coefficient, were either 0.11 (assuming $T_M = 5$) or 0.05 (assuming $T_M = 10$).

$$K = -(\mathrm{Ln}(1 - L_m / L_\infty)) / (T_M - T_0) \qquad (2)$$

Given the uncertainty in age estimates, further research is required to elucidate the growth dynamics of Cusk.

Reproduction

Oldham (1972) reported a range in fecundity of 100,000 eggs in a 56 cm fish to 3,927,000 eggs in a 90 cm fish.

Observations of the occurrence of ripe and spawning maturity stages in commercially landed fish during 1964 indicated that most Cusk spawning took place in the last half of June but that the spawning season lasted from May to August (Oldham 1972). Catches of Cusk eggs in Scotian Shelf ichthyoplankton Program (SSIP) surveys during the late 1970s – early 1980s confirm Oldham's results, with eggs abundant in plankton net hauls in June and July with smaller quantities taken in May and August and occasional catches as late as September (Figure 16). Also, port samplers examining catches from the western Scotian Shelf and Gulf of Maine have observed Cusk in spawning condition as early as March (Harris and Hanke 2010). Similar ichthyoplankton surveys conducted by the USA in the Gulf of Maine – Georges Bank area at about the same time (Berrien and Sibunka 1999) found eggs from March to November but most occurred in May-June, slightly earlier than in Canadian waters. Cusk eggs were observed largely over the western Scotian Shelf and Gulf of Maine in areas where adults were caught in the summer bottom trawl survey.

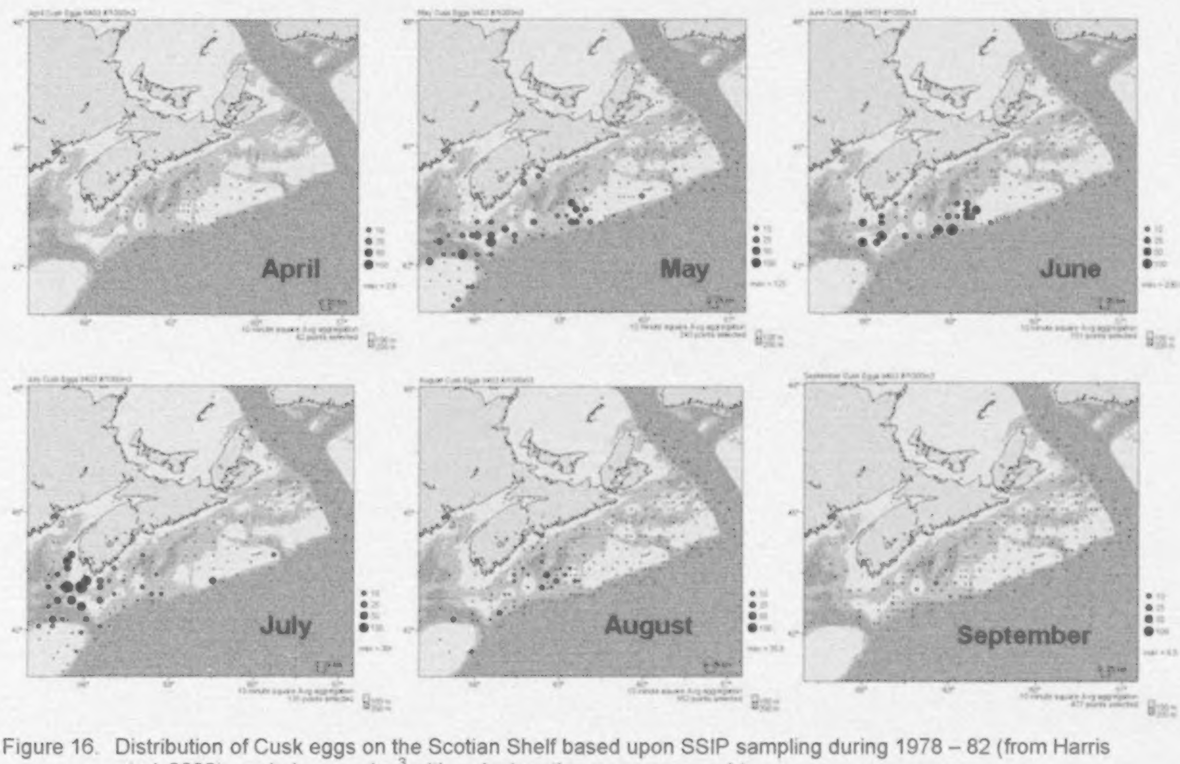

Figure 16. Distribution of Cusk eggs on the Scotian Shelf based upon SSIP sampling during 1978 – 82 (from Harris *et al.* 2002); scale in eggs / m^3 with + designating no. eggs caught.

Cusk were caught in the vicinity of Emerald Bank in the bottom trawl surveys during the same period that the SSIP surveys were conducted (Figure 6). Very few Cusk have been caught in the bottom trawl surveys in more recent years. This suggests a spawning component of the population may have been lost.

Ichthyoplankton surveys by the USA confirm that eggs occur throughout Gulf of Maine waters, i.e. in 5Y as well as 4X, and on the slopes of Georges Bank, including its southern edge (Berrien and Sibunka 1999). These data also show an apparently disjunct spawning area at 36-38^{0}N, with eggs occurring at this southern location persistently over several months. In addition, USSR ichthyoplankton surveys on Flemish Cap in 1978-83 caught Cusk eggs in late April and in May (and in one case in March) and one larva (Serebryakov *et al.* 1987). Thus, egg distributions within the main area of adult distribution are widespread, consistent with Oldham's conclusion that there are not clearly defined, discrete spawning grounds. Nonetheless, maps of egg distributions suggest that the northeastern Gulf of Maine is an area of particularly high egg abundance. It appears that there are also discrete spawning populations on Flemish Cap and in the Mid-Atlantic Bight off Virginia (Halliday 2006).

Eggs, which are about 1.1-1.5 mm in diameter, are pelagic. Larvae hatch at about 4 mm and remain in the upper part of the water column until about 50 - 60 mm, at which time they become benthic (Collette and Klein-MacPhee 2002). Larvae have been captured from Emerald Bank south to Long Island in DFO and USA ichthyoplankton surveys. Larvae are distributed widely over banks (Colton and St. Onge 1974, Halliday 2006) but in the same general area as the eggs, and have been observed in association with the jellyfish *Cyanea* (Colton and Temple 1961).

The duration of the early life history pelagic phase is not reported but likely depends on water temperature and is presumably comparable to other Gadids – about 1 - 4 months (COSEWIC 2003). The location of benthic nursery grounds is not known. Few Cusk under 30 cm have been caught in Canadian summer RV surveys (Halliday 2006) or in longline surveys.

Demersal juveniles and adults remain strongly associated with the substratum and do not swim up into the water column (Bigelow and Schroeder 1953, Collette and Klein-MacPhee 2002). As adults, Cusk are described as slow-moving, sedentary and solitary, and do not form large aggregations or schools (Svetevidov 1948, Wheeler 1969, Cohen *et al.* 1990).

Predator – Prey Associations, Condition and Natural Mortality

Halliday (2006) reports that Spiny Dogfish (*Squalus acanthias*) is the most frequently recorded predator of Cusk. Predation by Winter Skate (*Leucoraja ocellata*), Atlantic Cod, White Hake (*Urophycis tenuis*), Atlantic Monkfish (*Lophius americanus*), Cusk-eel (*Lepophidium cervinum)*, Sea Raven (*Hemitripterus americanus*), Summer (*Paralichthys dentatus*) and Windowpane Flounder (*Scophthalmus aquosus*) has been observed in US waters (Collette and Klein-MacPhee 2002). There are occasional records of predation by Cod and Atlantic Halibut on the Scotian Shelf (Harris and Hanke 2010, Harris *et al*. 2002). Cusk are a very small part of the diet of Grey Seals (*Halichoerus grypus*) (Bowen *et al*. 1993, Bowen 2011) although there is little information available on the diet of Grey Seals in NAFO Div. 4X, where Cusk primarily reside. So this could reflect a geographic sampling problem (Bowen 2011) and Grey Seals could be a predator in this area.

Northwest Atlantic observations of Cusk diet are limited due to the propensity of their stomachs to evert when brought to the surface (Scott and Scott 1988, Bergstad 1991). The available data indicate that food consists primarily of Crustacea, particularly crabs, shrimps and euphausiids (krill), fish (species not recorded) and echinoderms (brittlestars) (Langton and Bowman 1980, Bowman *et al*. 2000, Harris and Hanke 2010, Harris *et al*. 2002). Off Norway, diet is similar, consisting of crustaceans (shrimp and Norway Lobster), small fish (Norway Pout (*Trisopterus esmarkii*), Atlantic Halibut and redfish (*Sebastes sp.*)) and polychaete worms (Magnússon *et al*. 1997).

Fish condition can give some indication as to the feeding success or otherwise of Cusk. However, data on weight at length of individual fish were collected irregularly on DFO summer bottom trawl surveys with no collection during 1986-98 and very small numbers of observations recently. The annual weight of a 65 cm Cusk is shown in Figure 17. During the late 1970s and 1980s the weights were generally above 2.8 kg. In more recent years the weights have been between 2.6-2.8 kg. It is difficult to state with confidence whether this is an important trend in fish condition.

Figure 17. Change in weight (kg) of 65 cm Cusk during 1970 – 2010.

There is no information on the natural mortality (M) rate of Cusk. It is, however, likely a relatively long-lived species (see above) and thus natural mortality could be expected to be similar to other large Gadiformes such as Cod and Haddock, i.e. in the vicinity of 20% per year under normal conditions. Pauly (1980) provides a relationship (equation 4) between natural mortality (M), K, the Brody growth coefficient and mean annual temperature experienced by a fish (T).

$$\ln(M) = -0.0152 - 0.279 \ln L_\infty + 0.6543 \ln K + 0.4634 \ln T \quad (4)$$

Mean average bottom temperature during 1970 – 2010 in NAFO Div. 4X, based upon the DFO summer survey is 7.2 °C. While this is during the summer, the annual average is not expected to be much lower, in the order of 6 °C. This provides an estimate of M of 0.14 or 0.09 depending upon whether K is 0.11 (age 5 maturity) or 0.05 (age 10 maturity). This compares with estimates based on the formula (M = 1.5 x K) of Jensen (1996) of 0.17 and 0.08 for age 5 and age 10 maturation respectively. It is important to note that adult Cod and Haddock on the eastern and western Scotian Shelf have experienced relatively high rates of natural mortality (in the order of 0.5 – 0.8) in the late 1980s and through the 1990s (Worcester *et al.* 2009). The extent to which the stocks of these and other species such as Cusk that occur in the western Scotian Shelf/Gulf of Maine area experienced a coincident elevation in natural mortality rates is not known.

Generation Time

The current aging data for Northwest Atlantic Cusk suggest that the age of 50% maturity is about 5. If natural mortality is about 0.14, generation time is $T_M+1/M = 12.1$ years. If on the other hand, the age of 50% maturity is about 10 and M about 0.09, generation time is 21.1 years. The shorter generation time of 12.1 years will be used in this assessment because the new aging data have not been corroborated by further analyses.

Dispersal and Migration

Cusk appear to be a relatively slow moving, sessile species that does not undergo extensive local movements, seasonal, or spawning migrations. In the Northwest Atlantic, spawning occurs over banks similar to other Gadid species, with likely retention of passively drifting eggs and larvae by gyres with subsequent localized settling and active movement to preferred rocky habitat areas. Fragmentation between isolated populations within Canada does not appear to be an issue given the highly localized distribution of the species in the Gulf of Maine area.

Interspecific Interactions

There has been limited consideration of the role of Cusk in aquatic food webs off the east coast of Canada. Ecopath modelling (Bundy 2004, 2005) of the Scotian Shelf considered Cusk along with other demersal piscivores such as White Hake and Sea Raven. This modelling indicated that juveniles and adults have trophic levels of 3.95 and 4.2 - 4.4 respectively. No special feeding relationships were noted. As noted above, Atlantic Cod and Atlantic Halibut are likely predators.

POPULATION SIZES AND TRENDS

Sampling Effort and Methods

While a number of fishery independent surveys have been conducted in the species range of Cusk, only a relatively small number are suitable for estimation of trends in Cusk abundance and biomass. These include:

- DFO summer bottom trawl survey
- NMFS fall bottom trawl survey
- Industry Atlantic Halibut survey

The NMFS spring bottom trawl survey is also useful but it is a shorter series than the fall survey. As the two series exhibit similar trends, focus in this assessment is placed on the fall survey. In addition to these surveys, commercial catch rates (CPUE) of the longline fleet operating in NAFO Divisions 4X and 5Z have been used as estimates of biomass trends (Harris and Hanke 2010).

The DFO summer bottom trawl survey has been conducted every July – August since 1970. Employing a stratified – random design and standardized sampling protocol (Halliday and Kohler 1971), about 200 bottom trawl sets are annually made on the Scotian Shelf. Over the duration of the time series, the sampling effort has increased. The spatial distribution of the strata was described earlier. Harris and Hanke (2010) consider that this survey does not representatively sample the population because the survey does not sample rocky bottom areas, the preferred habitat of Cusk. It was argued that as Cusk abundance changes, it will either spread out from this habitat (high abundance) or retreat to these areas (low abundance). This can lead to hyperdepletion where the survey index declines faster than the population biomass, implying that survey catchability, q, is a function of Cusk abundance. This hypothesis was tested in population modelling by Davies and Jonsen (2011), who considered it to be supported by the information available. This is discussed further below.

The NMFS fall bottom trawl survey has been conducted every October – December since 1963. Also employing a stratified-random design and standardized sampling protocol (Grosslein 1974), the survey annually undertakes about 350 bottom trawl sets in the Gulf of Maine area. Harris and Hanke (2010) contend that this survey suffers the same catchability issue as the DFO survey.

The industry Atlantic Halibut survey is conducted during late May – late July every year since 1998 using both a commercial and fixed station design. For the purposes of this assessment, only the data from the fixed stations that have been consistently occupied (which reside in 4VWX) have been used. The protocol of the Halibut survey is discussed by Trzcinski *et al.* (2011). As the protocol was in development during the first year (1998) of the survey, these data are not used in this assessment. Also, while set catch was standardized to 1000 hooks, no standardization for soak time was undertaken. This is consistent with the treatment of these data by Harris and Hanke (2010). Sampling has averaged about 55 stations per year with little variation.

As in COSEWIC (2003), commercial landings and effort data for longline vessels were used to estimate an annual CPUE (tons per trip) index of mature biomass. Longliners deploy their gear in a variety of habitats including deep water along the edge of the continental shelf and in rocky bottom areas that may not be well sampled by survey trawls.

Developing a catch per unit effort (CPUE) index requires careful data selection to avoid potential biases introduced by fishing. The design of the CPUE index here is based upon that of Harris *et al.* (2002) and Harris and Hanke (2010) with some minor modifications. In their analysis, Harris and Hanke (2010) limited the CPUE data to NAFO Div 4X, excluding those in 5Z. The number of trips made in each area has been similar since 1986, except in the mid-1990s when effort in 5Z was considerably lower. Given the distributional range of Cusk, it was decided to use both the 4X and 5Z data in this assessment.

Longline vessels operating in this area target a range of groundfish species including Cod, Haddock, and Pollock. Cusk are generally a bycatch to this fishing. Prior to 1999, a longline fishery for 'shack' has been recognized, which was directed for Cusk and White Hake combined. Consistent with Harris and Hanke (2010), all trips that caught any of these five species, regardless of the target species, were used in the CPUE index.

Harris and Hanke (2010) reported that the reliability of data prior to 1986 was questioned anecdotally, presumably by fishermen, when a landing cap of 1000 t for Cusk was implemented. Previously, there was no landing limit for Cusk. It has been suggested that other species, such as Atlantic Cod, were reported as Cusk when target species quotas were exceeded. As well, misreporting and discarding were considered prevalent in the fishery. For this reason, they did not use the CPUE data prior to 1986. In 2003, the landing cap was reduced to 750t where it has remained. Here, the 1986 – 2010 CPUE data are used in the CPUE index.

Harris and Hanke (2010) based their CPUE index on the data from tonnage class two and three vessels. Tonnage class 2 and 3 vessels consistently contributed about 50 - 60% of the longliner fleet's landings until the mid-1990s after which time, their share declined to the 20% level observed more recently (Figure 18). The contribution of small tonnage class zero and one vessels has, on the other hand, increased. Reliable effort data for these smaller vessels do not exist. The data for the TC 2 and 3 vessels were considered adequate to estimate a CPUE index.

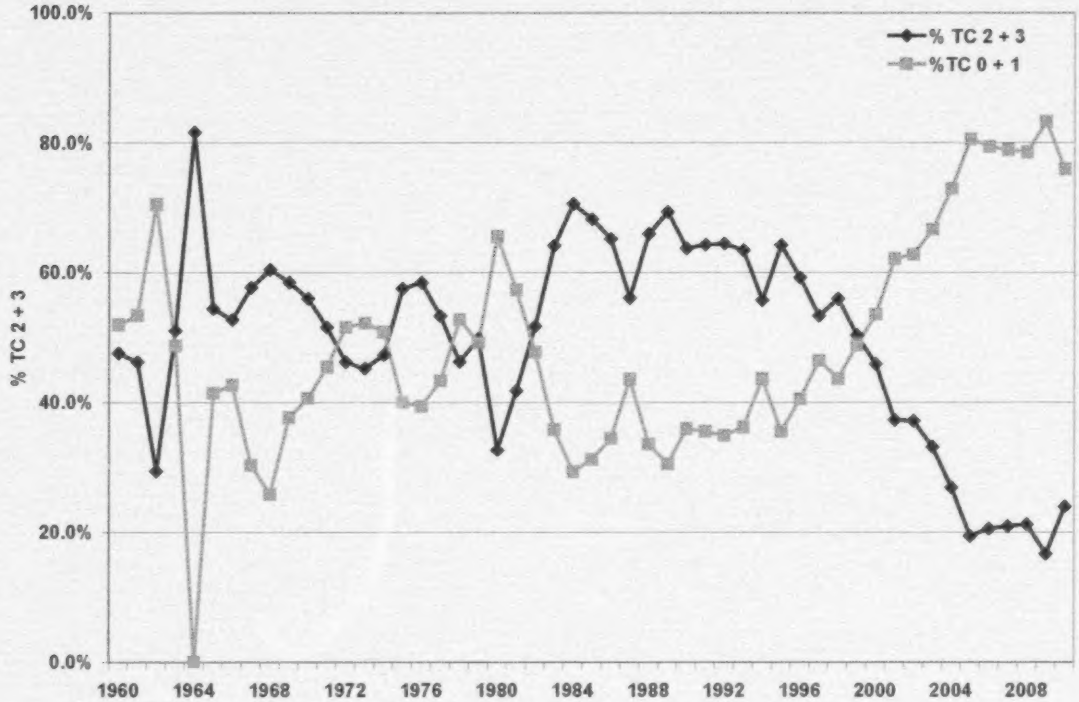

Figure 18. Share of longline fleet landings in all NAFO areas by tonnage class.

Harris and Hanke (2010) produced their CPUE index through averaging of monthly catch rates of tonnage class two and three longliners operating in NAFO Div 4X during July – September. There have been significant changes over the time series in the months during which the fishery occurs, with it becoming focused in July – September since the late 1990s. To ensure consistency of the time series, as with Harris and Hanke (2010), the analysis of the CPUE data was limited to these months.

For the subset of selected data since 1986, there has been a significant decline in the number of trips (Figure 19) with current levels (278) being well below peak values (1500 – 2500) in the early 1990s.

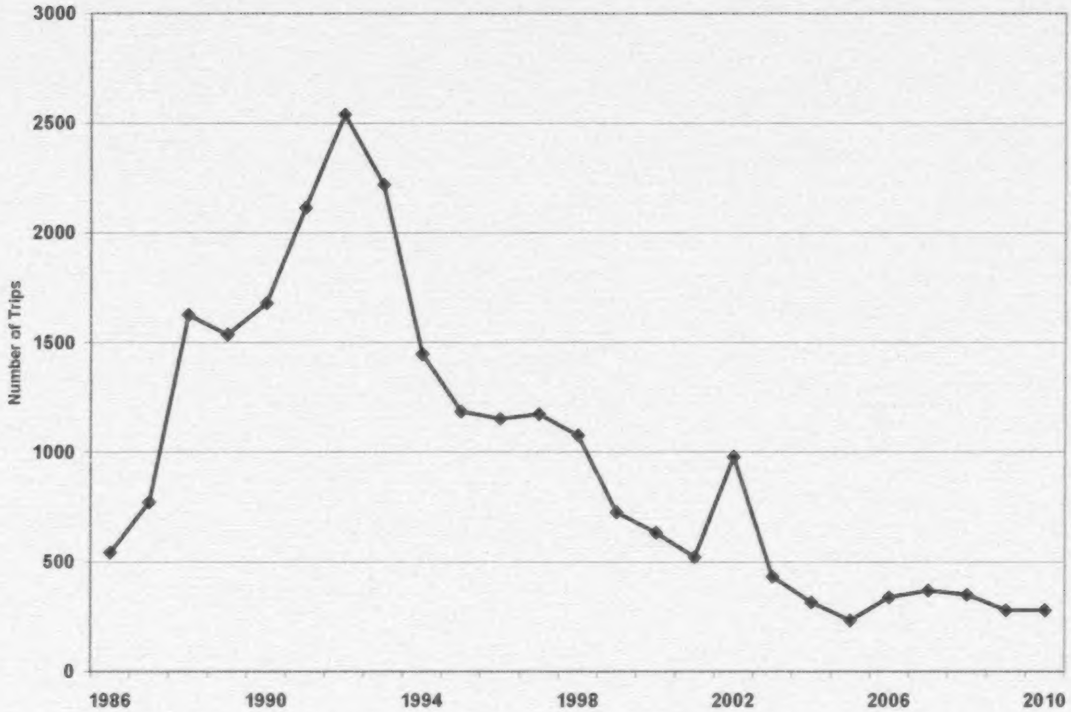

Figure 19. Trend in annual number of trips fished by tonnage class 2 and 3 longlines in NAFO Divs. 4X and 5.

Very little observer information is available for this fleet (Table 6). Since 1985, only 314 of the possible 24,516 trips have been observed. In addition, there were even fewer trips where length measurements of Cusk were taken. Therefore, the DFO Maritimes Science port sampling data were used to characterize longline landings size composition. An overview of port sampling intensity is given in Table 7. Since 1960, 459 samples have been taken with the majority of these since the mid-1990s. Sampling was focused on the longline fleet with few samples on trawl and gillnet landings and no samples of traps and other gears.

Table 6. Number of longline and trawl trips with observer coverage during 1977 - 2011 in NAFO Div. 4X5.

	Longline	Trawl	Total
1977		1	1
1978		16	16
1979		5	5
1980		47	47
1981		42	42
1982		26	26
1983		17	17
1984		20	20
1985	2	7	9
1986		11	11
1987		25	25
1988		31	31
1989		60	60
1990	2	55	57
1991	1	64	65
1992	6	52	58
1993		57	57
1994	33	31	64
1995	21	42	63
1996	15	25	40
1997	2	7	9
1998	7	10	17
1999	7	10	17
2000	58	31	89
2001	24	18	42
2002	6	23	29
2003	8	12	20
2004	17	20	37
2005	16	14	30
2006	3	9	12
2007	6	14	20
2008	10	8	18
2009	7	5	12
2010	55	21	76
2011	8	15	23
Total	314	851	1165

Table 7. Number of DFO Maritimes Science commercial port samples of Cusk by gear (otter trawl, line and gillnet) and quarter during 1960 – 2010.

	Otter Trawl				Line				Gillnet			
	Qtr 1	Qtr 2	Qtr 3	Qtr 4	Qtr 1	Qtr 2	Qtr 3	Qtr 4	Qtr 1	Qtr 2	Qtr 3	Qtr 4
1960												
1961								2				
1962					1	1		1				
1963												
1964	1											
1965												
1966												
1967												
1968												
1969												
1970												
1971												
1972							1					
1973												
1974												
1975						2						
1976						2						
1977												
1978					1	2						
1979						2						
1980						1		3				
1981					3	1	1	1				
1982												
1983							3					
1984							2					
1985							2	2				
1986							1					
1987						3						
1988						1					1	
1989								1				
1990												
1991						1	1					
1992												
1993						1	1	1				
1994						2	2					
1995					1	4	7	8		1		
1996						2	7	2				
1997						6	7	3				
1998					1	7	8	4				
1999	2				1	2	7	2				
2000		2	1	1	2	2	6	9				
2001			2		6	5	15	11	2	2		
2002		2	1	1	5	2	17	9				
2003	2	2	1	1	3	7	21	24				
2004			1		11	8	9	5				
2005		1				6	11	3				

	Otter Trawl				Line				Gillnet			
	Qtr 1	Qtr 2	Qtr 3	Qtr 4	Qtr 1	Qtr 2	Qtr 3	Qtr 4	Qtr 1	Qtr 2	Qtr 3	Qtr 4
2006	2	1				3	11	4				
2007		1	1		1	7	14			1		
2008		1				5	17					
2009	1	1				3	13	7				
2010	1	2			2	4	9	2		1	1	

Abundance

Table 8 summarizes the abundance indices of the DFO summer bottom trawl survey. These were estimated for the whole survey area (4VWX) rather than just for 4X, as was done by Harris and Hanke (2010). While the two series are very similar, it was considered that the broader area index was more representative of abundance trends for the entire DU. This survey indicates a significant decline in mature (42 cm+) numbers since the start of the time series (Figure 20). The average indices in the survey since the last COSEWIC assessment (2002-2010) are lower than from the 9 years prior to that assessment (1993-2001). The average mature numbers declined from 341,000 to 218,000 while the mature biomass declined from 695 t to 407 t. These are underestimates of the true abundance and biomass because Canadian landings annually averaged 865 t over the 2002-2010 period and between 250-300 t was estimated to have been discarded annually in the Lobster fishery (see section on Threats and Limiting Factors). Thus, current catch is well in excess of the minimum estimates of mature biomass from the DFO summer bottom trawl survey. Therefore, these are considered minimum estimates of abundance and biomass and they are taken as an index of relative abundance.

Table 8. Abundance (000s) and biomass (t) indices of Cusk from DFO summer bottom trawl survey.

	Abundance		Biomass		
	Mature	Total	Mature	Total	CV
1970	1829.503	2044.741	6441.222	6557.508	20.3%
1971	2843.885	2957.624	7437.100	7495.565	46.2%
1972	2870.328	2870.328	10039.186	10039.186	37.0%
1973	3160.945	3203.869	8720.577	8722.332	24.8%
1974	3702.474	3782.555	9783.806	9809.546	24.2%
1975	3459.578	3530.611	11093.108	11113.471	25.0%
1976	2961.421	3126.953	8623.228	8713.713	12.4%
1977	3587.545	3844.561	10149.489	10257.066	19.8%
1978	2644.550	2748.565	7847.673	7901.067	32.2%
1979	3001.852	3118.384	8178.303	8230.481	22.9%
1980	1233.797	1233.797	3350.709	3350.709	34.7%
1981	2481.629	2575.612	7526.568	7560.658	32.7%
1982	2441.037	3147.285	7623.891	7865.671	26.7%
1983	1374.181	1544.202	4079.546	4146.062	26.3%
1984	2732.205	3166.324	7340.293	7491.847	13.9%

	Abundance		Biomass		
	Mature	Total	Mature	Total	CV
1985	1267.487	1459.862	3644.892	3705.846	32.3%
1986	1106.484	1147.062	3368.056	3381.825	32.0%
1987	2699.241	2766.737	7190.718	7226.211	31.2%
1988	2100.383	2325.101	5900.804	6000.568	28.5%
1989	1387.025	1393.451	4305.056	4307.103	32.9%
1990	1270.969	1270.969	2717.908	2717.908	23.1%
1991	3064.672	3126.847	6376.251	6416.966	43.9%
1992	655.735	728.758	1815.513	1856.899	44.9%
1993	382.190	382.190	703.751	703.751	35.6%
1994	181.059	353.370	446.576	525.009	42.7%
1995	248.028	361.283	776.692	784.773	60.5%
1996	263.061	354.009	628.338	653.302	42.6%
1997	467.040	676.326	901.447	932.915	40.1%
1998	250.518	344.892	481.910	518.700	26.7%
1999	295.578	354.110	668.428	695.501	48.7%
2000	458.276	546.294	824.371	879.133	80.4%
2001	525.613	584.818	827.085	850.003	37.5%
2002	273.982	318.393	668.819	670.767	74.0%
2003	91.065	158.468	114.577	146.847	41.9%
2004	249.024	268.884	474.030	481.120	38.7%
2005	252.497	252.497	355.557	355.557	39.4%
2006	223.364	338.303	502.566	561.873	50.5%
2007	341.014	539.651	537.400	655.990	70.1%
2008	41.889	119.995	106.299	119.941	62.4%
2009	29.434	29.434	47.977	47.977	100.0%
2010	458.260	526.501	856.124	898.740	20.8%

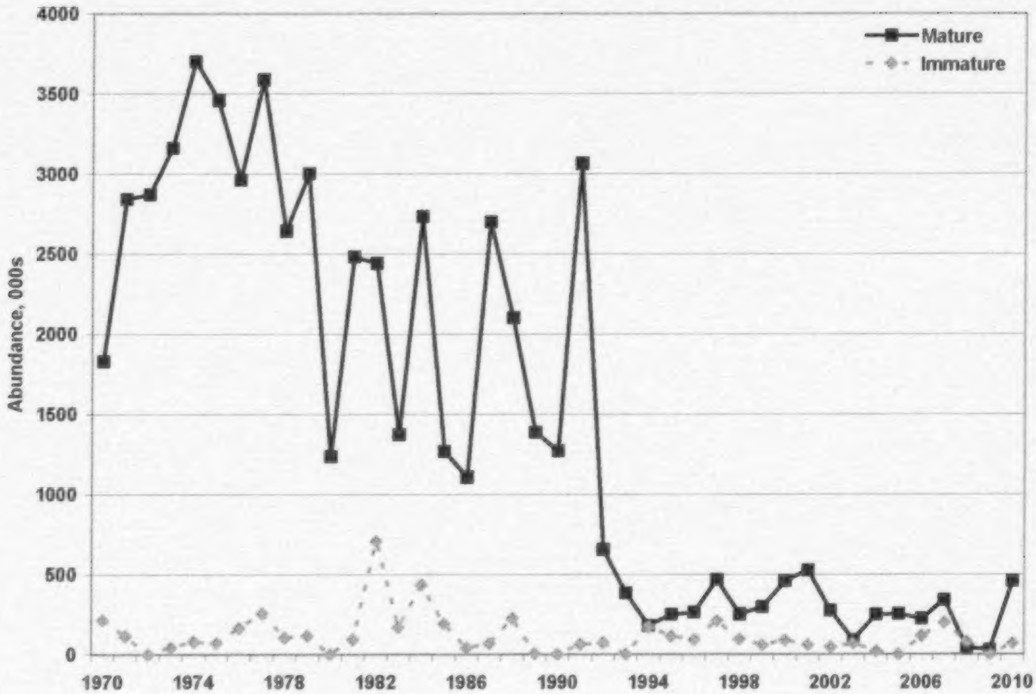

Figure 20. Trend in abundance of immature (<42 cm) and mature (42 cm+) Cusk in NAFO Divs 4VWX, based upon DFO summer bottom trawl survey.

The length composition of Cusk taken in the trawl survey has contracted over the 40-year time series (Figure 21). In the 1970s and 1980s, the population on the Scotian Shelf was dominated by 55 cm + individuals. Since then, abundance of these length groups has declined considerably in comparison to the smaller fish.

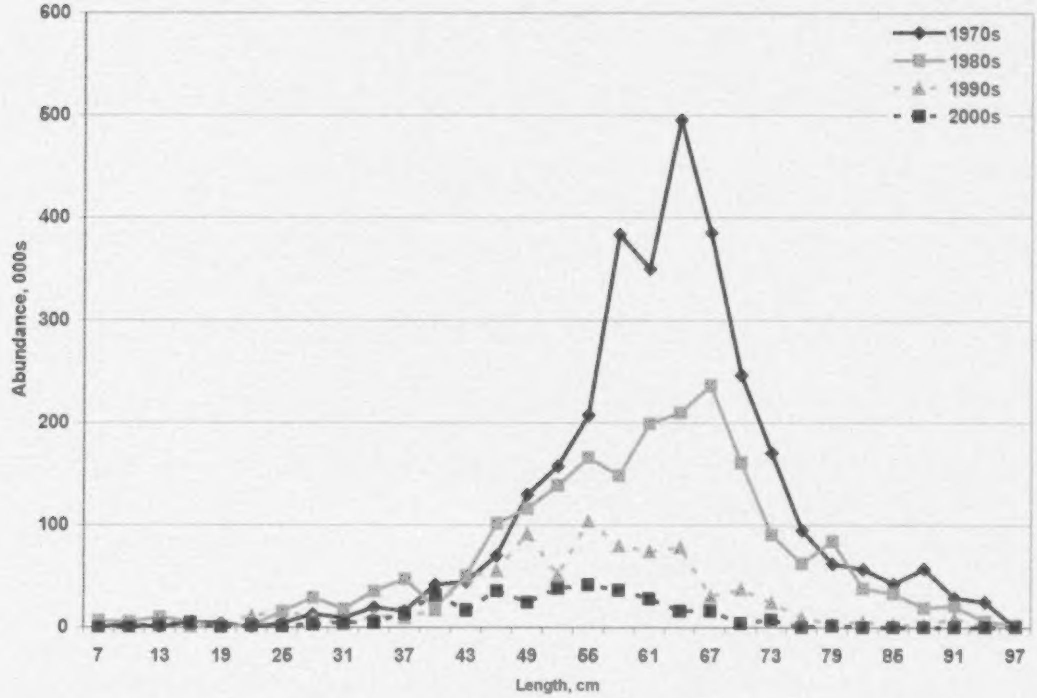

Figure 21. Decadal change in length frequency of Cusk in NAFO Div 4VWX as observed by DFO summer bottom trawl survey.

Table 9 summarizes the NMFS fall bottom trawl survey indices. The trends and CVs are similar to those in the DFO summer survey (Figure 22). The fall survey provides a minimum estimate of current abundance in the order of 450,000 individuals and a minimum estimate of mature biomass in the order of 580. Note that again these data are considered as relative and not absolute estimates of abundance and biomass.

Table 9. Abundance (000s) and biomass (t) indices of Cusk from NMFS fall bottom trawl surveys.

	Abundance, 000s			Biomass, t		
	Mature	Total	CV	Mature	Total	CV
1963	1580.0	1622.2	19.3	5138.2	5164.270	23.9
1964	670.2	752.94	30.0	2811.3	2813.950	35.9
1965	1047.6	1222.4	24.6	3302.0	3312.670	25.5
1966	1966.1	2336.3	25.9	8555.4	8583.950	30.4
1967	607.8	732.48	34.2	2308.2	2342.550	44.2
1968	990.3	1282.4	19.7	4448.1	4553.630	29.8
1969	956.0	1268.1	31.2	3299.5	3419.180	25.7
1970	1475.7	1630.4	20.4	4985.3	5048.060	20.3
1971	1118.3	1118.3	22.1	3987.3	3987.250	28.3
1972	1905.7	2047	25.1	5559.8	5627.990	28.1
1973	1405.8	1606.8	21.9	4560.5	4645.970	22.6
1974	360.2	378.21	33.3	1091.1	1092.500	45.2
1975	1314.1	1382	25.6	4423.1	4465.740	25.5
1976	517.0	567.89	43.4	1458.2	1470.130	37.4
1977	1169.3	1258.1	19.0	5390.0	5447.100	19.6
1978	931.3	997.2	16.6	4930.1	4973.800	17.7
1979	687.0	704.3	18.7	3784.1	3787.850	19.5
1980	1067.7	1196.2	29.6	5233.9	5298.560	29.9
1981	619.1	813.83	25.5	2995.9	3076.680	31.6
1982	278.3	296.32	33.3	1068.0	1070.950	41.4
1983	761.3	863.06	29.2	2354.4	2394.590	25.4
1984	1046.1	1152.6	31.4	4308.3	4357.800	34.3
1985	1682.1	1857.4	30.5	5693.4	5792.070	28.1
1986	1410.1	1439.6	29.7	3957.0	3966.380	29.0
1987	680.4	680.39	28.7	2455.3	2455.270	30.1
1988	1163.0	1163	26.6	3445.4	3445.420	28.0
1989	326.2	388.69	55.7	1273.2	1287.960	53.0
1990	329.2	371.61	39.5	1080.5	1102.800	40.2
1991	369.4	460.17	35.9	1593.1	1621.470	32.4
1992	201.1	353.69	51.3	480.7	489.415	48.9
1993	305.6	332.38	39.7	1323.4	1327.900	42.5
1994	94.7	470.07	28.3	289.0	359.016	65.3
1995	80.3	247.55	47.8	328.2	360.729	68.9
1996	352.8	662.75	24.8	1095.1	1161.310	40.6
1997	530.0	733.08	32.6	1808.6	1871.510	37.9
1998	54.8	130.65	48.8	132.5	169.857	76.8
1999	368.5	481.12	31.6	481.8	523.890	37.4

	Abundance, 000s			Biomass, t		
	Mature	Total	CV	Mature	Total	CV
2000	142.5	268.64	45.6	195.1	228.273	63.4
2001	384.5	633.91	32.1	529.9	588.815	32.7
2002	331.1	412.23	34.5	1139.6	1159.970	57.5
2003	284.4	428.3	31.0	994.1	1050.870	56.6
2004	339.4	339.36	40.0	557.1	557.072	39.2
2005	317.8	368.71	44.9	530.3	554.945	32.3
2006	214.9	255.49	36.8	337.5	364.249	48.0
2007	42.2	42.16	99.9	29.5	29.512	99.9
2008	225.7	318.69	41.9	276.9	299.001	44.1
2009	201.1	201.06	36.7	366.7	366.655	42.1
2010	444.9	537.61	54.4	576.8	602.087	51.9

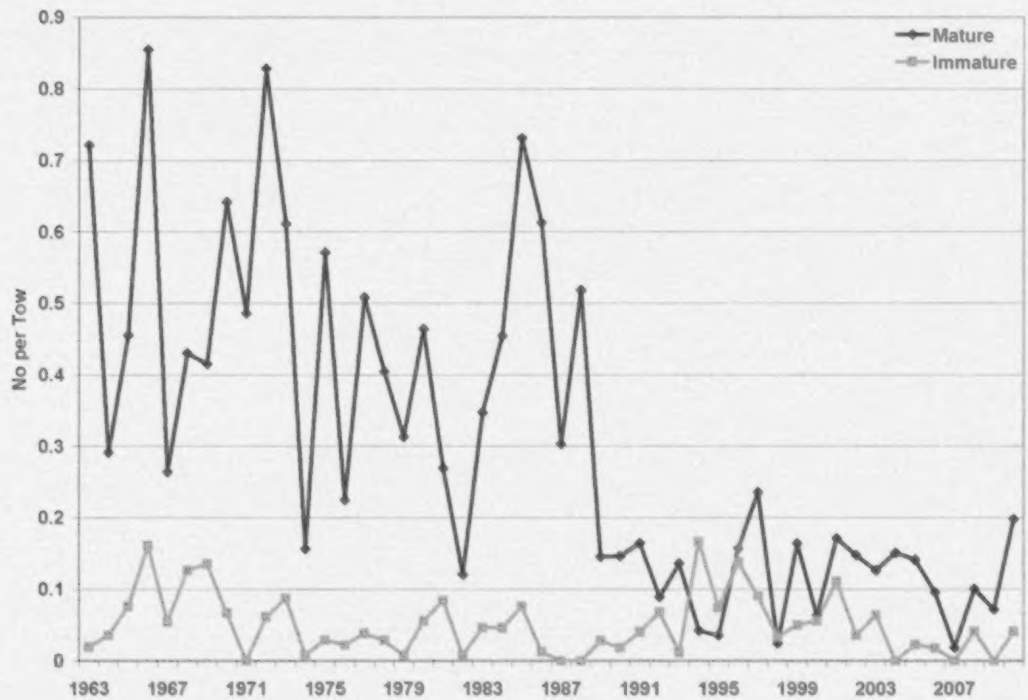

Figure 22. Trend in abundance of immature and mature (53 cm+) Cusk in NAFO Divs 5Z-6, based upon NMFS fall bottom trawl survey.

Similar decadal changes in length frequencies were observed in the NMFS survey as in the DFO summer survey (Figure 23), although the decline in mature individuals since 1988 is more evident in the NMFS fall survey.

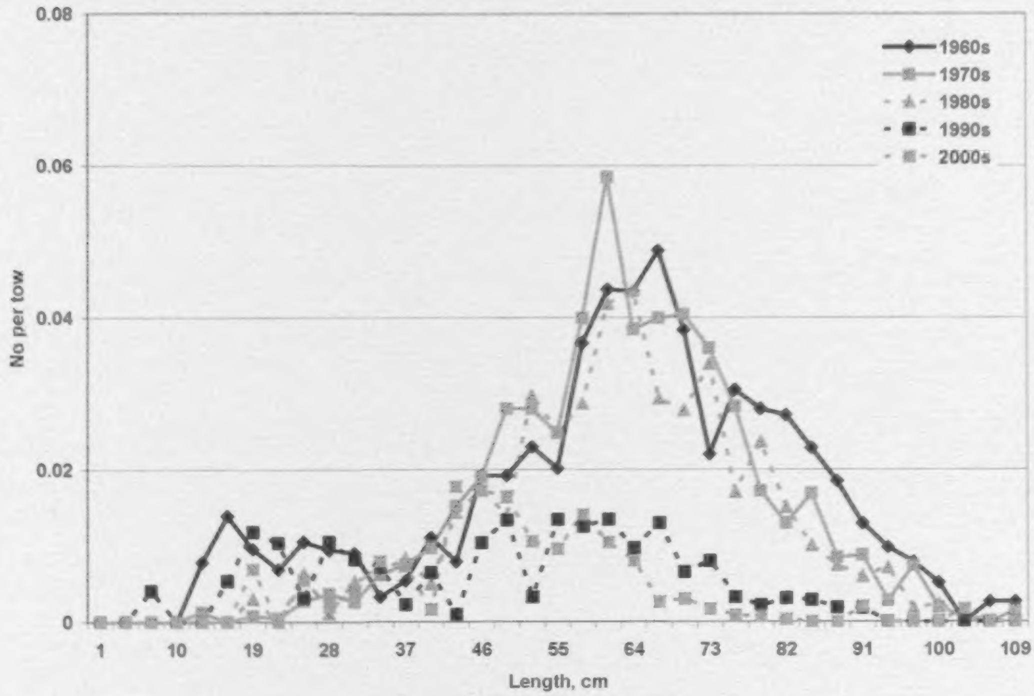

Figure 23. Decadal change in length frequency of Cusk in NAFO Div 5Z-6 as observed by NMFS fall bottom trawl survey.

Harris and Hanke (2010), in their analysis of Cusk catch rates in the Atlantic Halibut survey, averaged the kg/1000 hooks of the 53 core stations to produce annual estimates of a biomass index. This analysis was repeated here. In addition, two analyses using the core station results and GLM models were used. One assumed a lognormal error distribution and the other assumed a negative binomial distribution as was done for Atlantic Halibut (Trzcinski *et al.* 2011). The R code and diagnostics for both the linear and GLM models are provided in Appendix 2*. The indices of the three models are provided in Table 10 and the trends in Figure 24. The results of the negative binomial model were used in trend analysis.

*Appendix 2. Available upon request by contacting the Secretariat at: cosewic/cosepac@ec.gc.ca

Table 10. Indices of Cusk biomass estimated from Industry Atlantic Halibut survey. Units are undefined.

	Average	LM	GLM.NB
1999	13.51	11.37	13.79
2000	17.42	10.97	17.54
2001	12.28	8.30	9.86
2002	11.24	8.10	10.53
2003	11.52	8.08	9.96
2004	13.22	8.70	11.37
2005	11.95	8.76	10.58
2006	7.92	7.87	9.65
2007	16.45	12.46	15.94
2008	16.51	14.60	17.08
2009	15.03	10.29	15.51
2010	16.25	11.58	14.57
2011	26.94	9.04	14.21

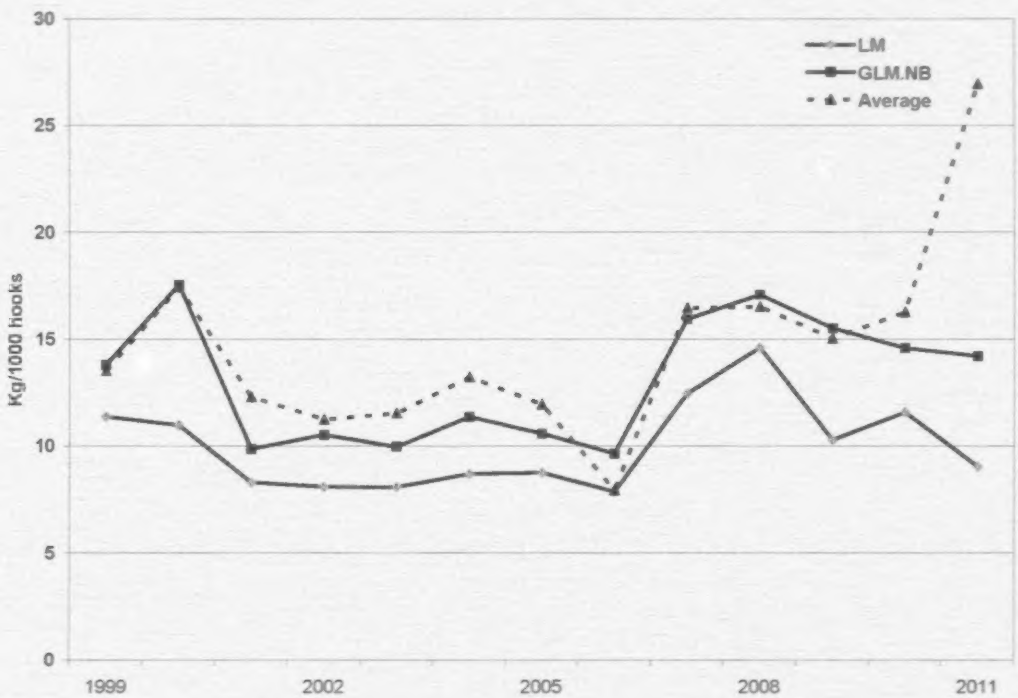

Figure 24. Trends in Cusk biomass indices (kg / 1000 hooks) based on Industry Atlantic Halibut survey. The legend is as follows: LM is the GLM estimate assuming lognormal error, GLM NB is the GLM estimate assuming negative binomial error (this is the index used in trend analysis), and Average is the simple mean of the fixed station catch rates.

The trends of the three indices are similar except for the 2011 increase in kg/1000 hooks observed in the average index. The fit of the models was poor (e.g. R^2 of 34% in the linear model) with influential observations evident. All models indicate a small decline at the beginning of the survey time series and a modest increase since 2006. There is some evidence of a recent declining trend. Overall, though, these effects are small with the overall trend being relatively flat.

Cusk lengths have not been consistently sampled on this survey although a reasonable amount of data is available. These data indicate that the Halibut survey has been catching almost exclusively mature (42cm+) Cusk throughout the times series (Figure 25). A comparison of size frequencies of the DFO summer and Halibut industry surveys for 2000 – 2010 indicates that the latter currently catches a significantly higher proportion of Cusk at lengths greater than 60 cm (Figure 26). These are sizes of Cusk seen by the DFO survey during the 1970s and 1980s (Figure 21). Indeed, this survey caught even larger Cusk at that time. Thus, the DFO trawl survey can catch this size of Cusk but does not appear to be doing so during the 1990s and 2000s.

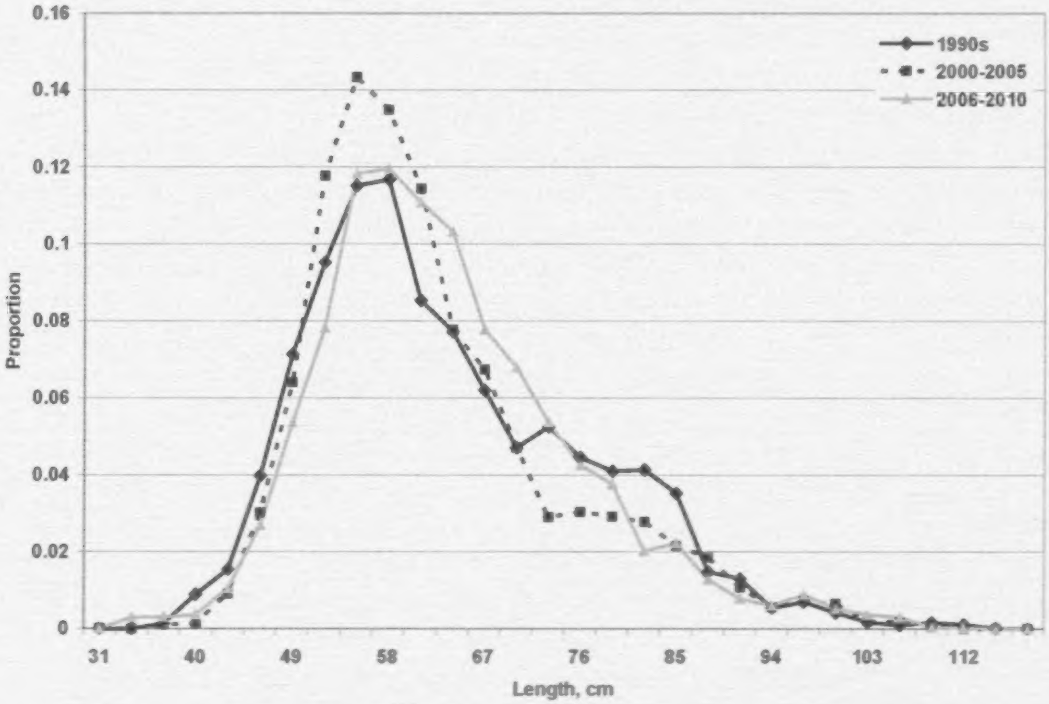

Figure 25. Temporal change in Cusk proportion at length in industry Atlantic Halibut survey.

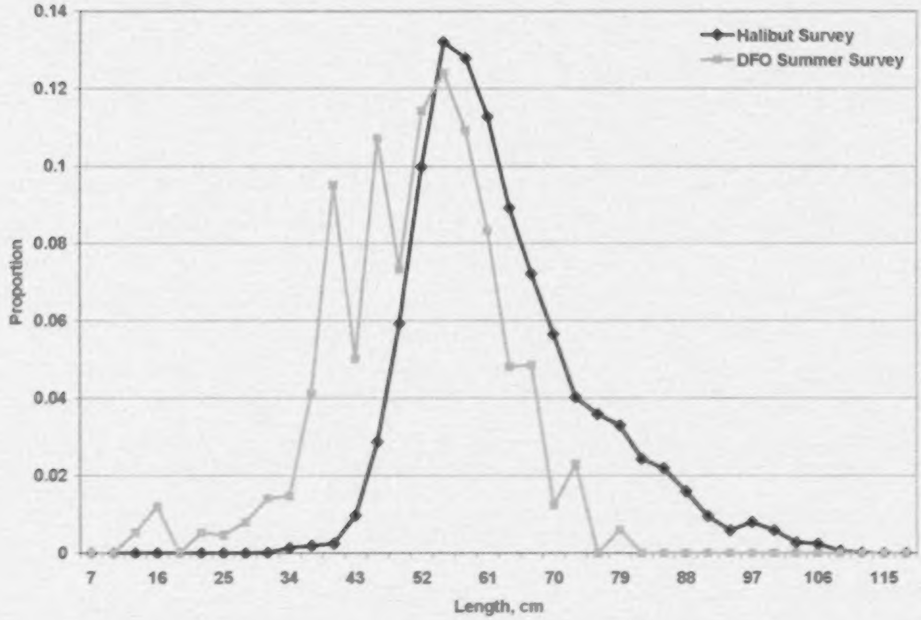

Figure 26. Comparison of Cusk average proportion at length observed in the Halibut and DFO summer trawl survey during 2000 – 2010.

A number of explorations of the commercial longline fishery's catch rates were undertaken, using month and unit area as factors in both linear and GLM negative binomial models. As observed by Harris and Hanke (2010), the model explorations did not produce satisfactory statistical fits (available upon request from the status report writer). Therefore, the NAFO Div 4X 5Z average was used as the preferred CPUE index of biomass (Table 11). Figure 27 compares this series to that of Harris and Hanke (2010) which is reported in Davies and Jonsen (2008). The two series indicate the same overall trend.

Table 11. Cusk catch rate indices based upon analysis of commercial tonnage class 2 and 3 longline catch rates (t/trip) in NAFO Div 4X – 5 during July – September.

	4X 5 CPUE Index
1986	1.100
1987	1.699
1988	1.152
1989	1.954
1990	0.846
1991	1.460
1992	1.669
1993	1.126
1994	0.377
1995	0.815
1996	0.594
1997	0.778
1998	0.794
1999	0.488
2000	0.669
2001	0.973
2002	0.888
2003	0.652
2004	0.571
2005	0.588
2006	0.371
2007	0.577
2008	0.426
2009	0.337
2010	0.335

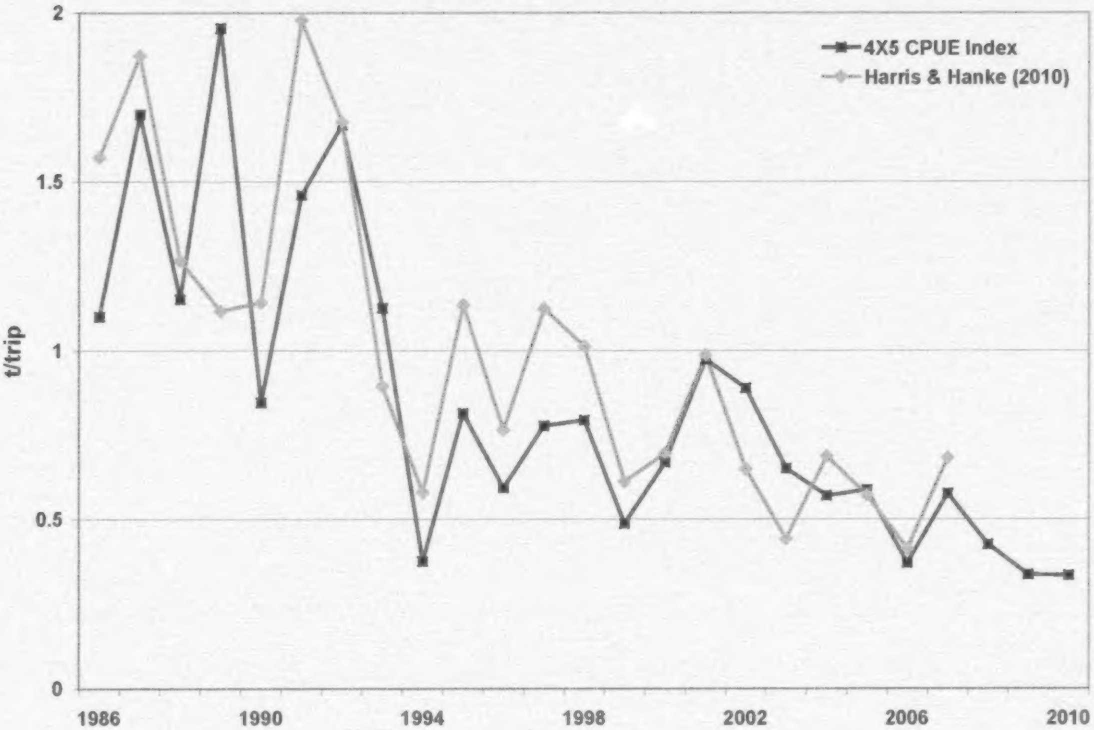

Figure 27. Trends in CPUE indices for tonnage class 2 and 3 longliners fishing in NAFO Div 4X5 during July – September; note that the Harris & Hanke (2010) index was only for NAFO Div 4X.

The commercial port sampling data indicate that the landings during quarter 2 and 3 reported by tonnage class 2 and 3 longliners consist of almost exclusively mature (>42 cm) individuals. Decadal changes in the size composition of the landings were evident (Figure 28). Modal size has become smaller, paralleling the trend in the DFO and NMFS surveys. There were some samples from 1961 – 62. Surprisingly, these indicated a smaller size range exploited than in the 1970s. This may indicate either inadequate sampling or changes in size composition not associated with population changes (e.g. regulatory changes).

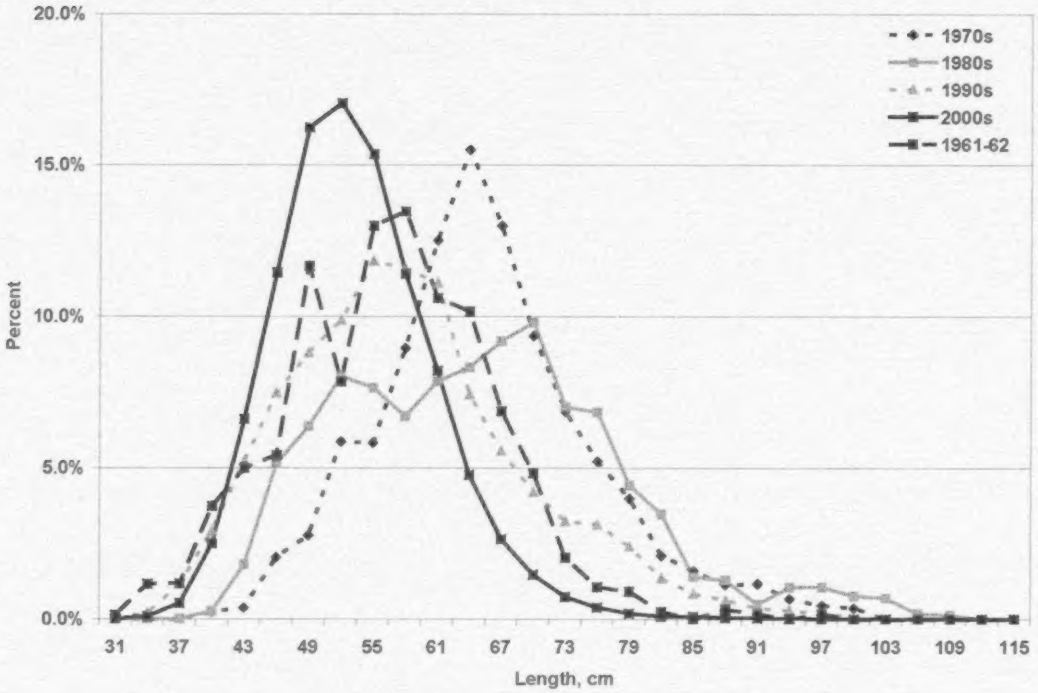

Figure 28. Decadal changes in landings of tonnage class 2 and 3 longliners operating in NAFO Div 4X5 during the 2nd and 3rd quarters of the year.

As indicated earlier, the declines estimated based on trawl survey results were considered to have been overstated (Harris and Hanke 2010) due to a possible relationship between trawl survey catchability and Cusk abundance (hyperdepletion): as abundance declines, Cusk may retreat to their preferred rocky habitat that is relatively inaccessible to the survey trawl gear. Davies and Jonsen (2008, 2011) explored the possibility of a change in trawl survey catchability with Cusk biomass using a Bayesian surplus production model (equation 6):

$$B_t = (B_{t-1} + rB_{t-1}(1 - B_{t-1}/K) - C_{t-1})\,\eta_t \qquad (6)$$

B_{t-1} and C_{t-1} denote biomass and landings in year t - 1 respectively, r is the intrinsic rate of population growth, K is the carrying capacity (population biomass at equilibrium before exploitation and η_t is a lognormal random variable with a mean of zero and variance σ^2 to account for stochasticity in population dynamics. The observation model (equation 7) incorporated a shape parameter to explore hyperdepletion in the survey indices:

$$I_{i,t} = q_i B_t^{\beta} \varepsilon_{i,t} \qquad (7)$$

$I_{i,t}$ is survey i in year t, q_i is the catchability of survey i, and β is the shape parameter. If β is less than one, hyperstability is indicated (the index declines at a slower rate than the populaton biomass; common in many fisheries). If it is above one, hyperdepletion is indicated (catch rate falls faster than biomass decline). Initial versions of the model (Davies and Jonsen 2008) explored a number of data inputs and configurations. Ultimately, they settled on using NAFO Div 4X landings, along with the 4X CPUE (average) index and the DFO summer bottom trawl survey to characterize Cusk population dynamics (Davies and Jonsen 2011). The industry Halibut and 4VsW sentinel surveys were not used, as they were uninformative of stock dynamics due to being short time series. While the estimated parameters of these models were highly uncertain, hyperdepletion in the trawl surveys was shown to improve model fit. Cusk biomass was estimated to have declined 59% during 1970 – 2001 and 64% during 1970 – 2007, substantially lower than the rate estimated when assuming survey catchability is independent of Cusk biomass.

This model (Appendix 3* - equivalent to Model 3 of Davies and Jonsen 2011) was updated with some changes. First, the 1970 – 2010 Canadian total catch from all sources, rather than the landings for NAFO Div 4X + 5, were used. This includes the discard data provided in the Threats and Limiting Factors section below. Second, the 1986 – 2010 CPUE index (average) for NAFO Div 4X+5 rather than just 4X was used (Table 11). Finally, the 1970 – 2010 DFO summer bottom trawl survey index of mature biomass for NAFO Div 4VWX rather than the stratified mean kg/tow for NAFO Div 4X was used (Table 8). Similar to Davies and Jonsen (2011), model convergence was tested using two chains (300,000 total iterations with 260,000 burn-in iterations and a thinning rate of 20) resulting in a Gelman – Rubin Diagnostic of Rhat = 1, providing strong evidence of convergence (Ntzoufras 2009). The model fit the two biomass indices without apparent trends in residuals (Figure 29). The posterior distributions of the model parameters are provided in Figure 30 and the trend in the annual proportion biomass of the carrying capacity (K) is given in Figure 31. A summary of the posterior quantiles of key model parameters is provided in Table 12.

*Appendix 3. Available upon request by contacting the Secretariat at: cosewic/cosepac@ec.gc.ca

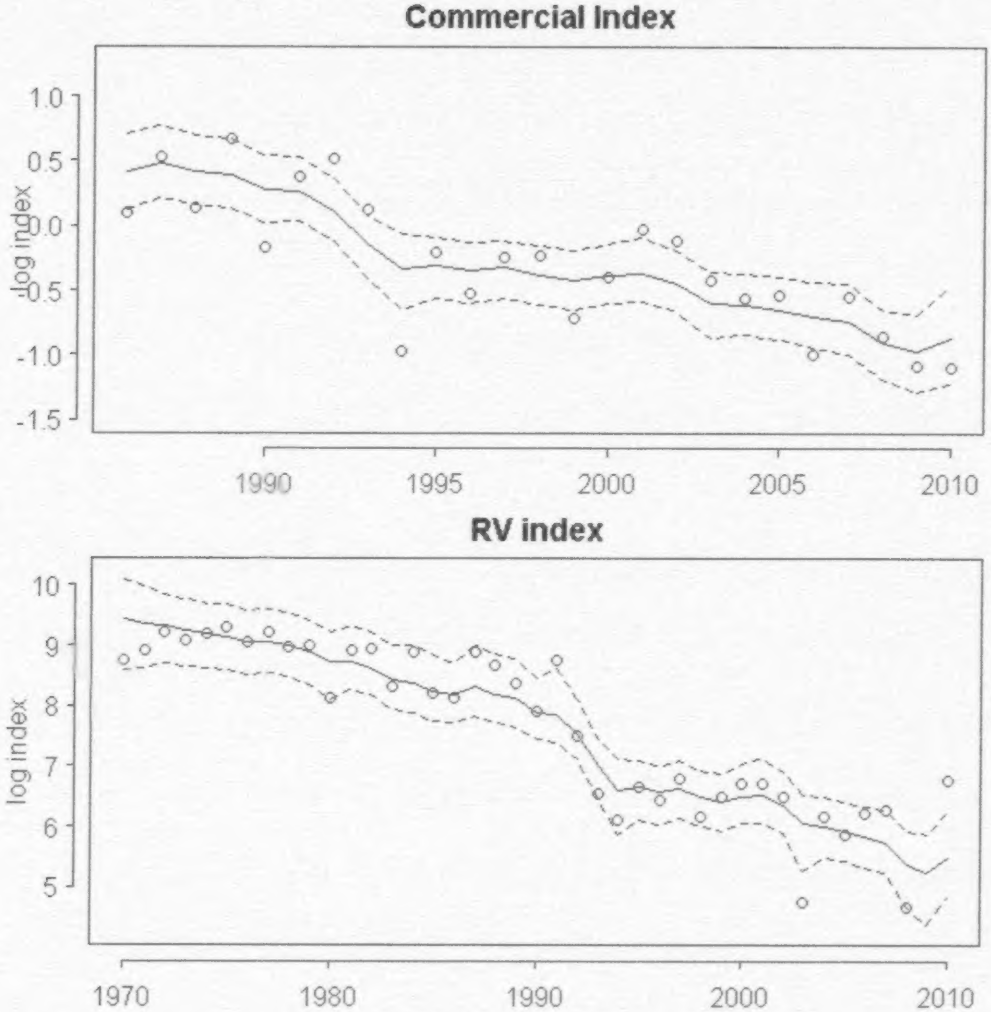

Figure 29. Observed (dots) and model predicted (lines) ln(indices) of Cusk biomass; 4X5 longline CPUE (top panel) and DFO summer survey (bottom panel).

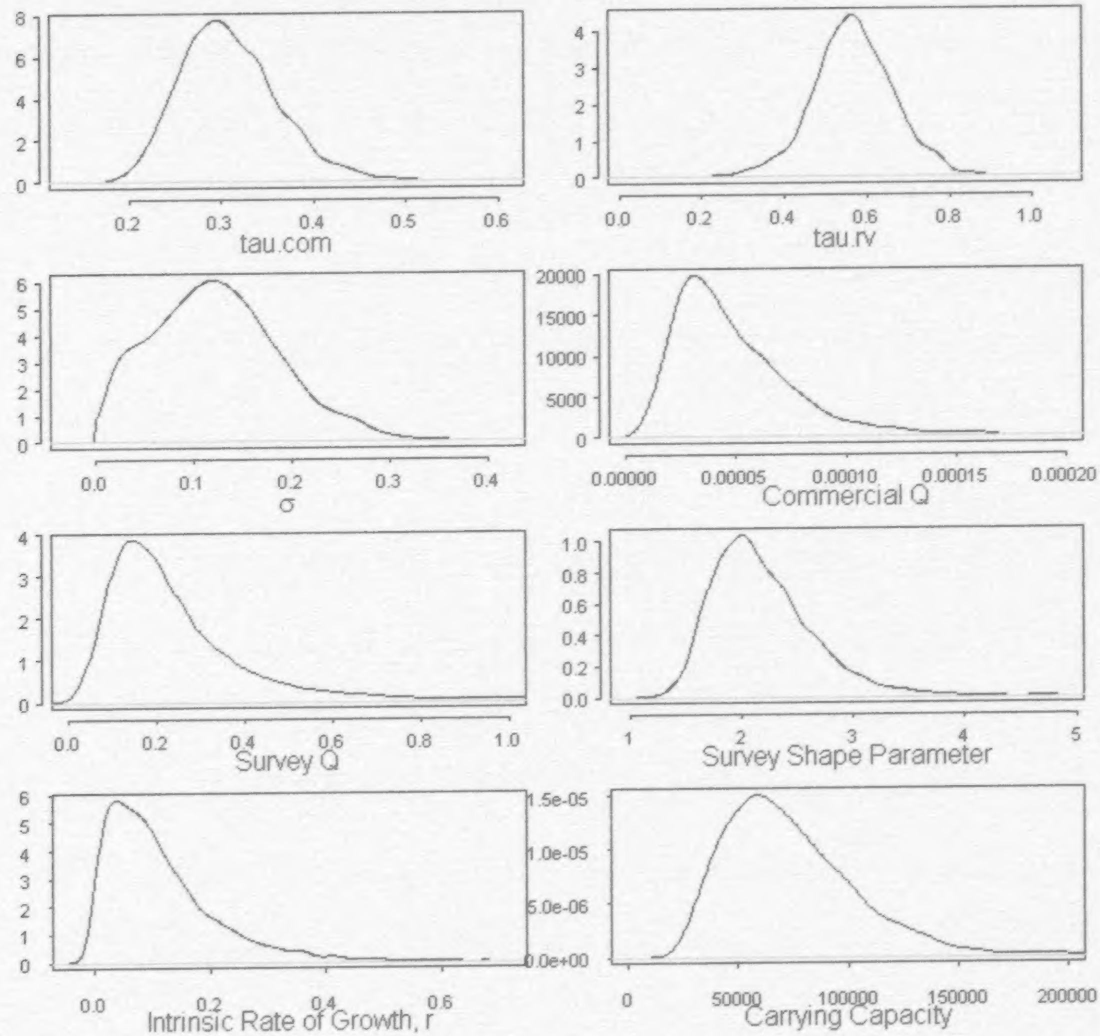

Figure 30. Posterior density plots of model parameters; tau.com and tau.rv are the observation error on the CPUE and DFO survey indices, σ is the process error, Commercial and Survey Q are the CPUE and DFO survey catchability; the remaining legends are self-explanatory.

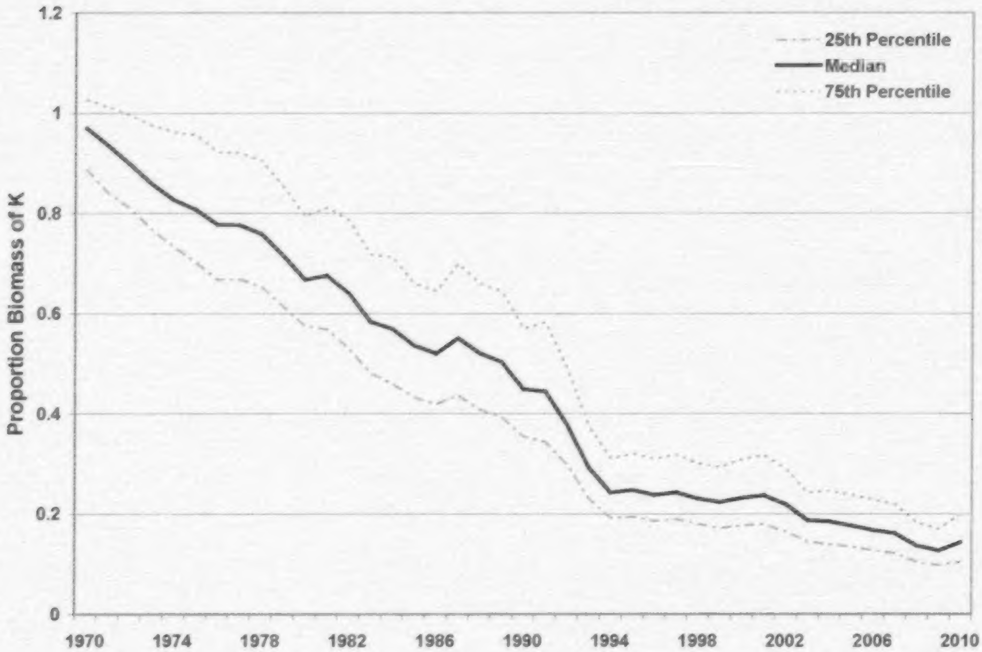

Figure 31. Trend in proportion that annual Cusk biomass is of carrying capacity (K) from state – space model; 25th, 5th (median) and 75th percentiles provided.

Table 12. Summary of posterior quantiles of parameters for Bayesian State – Space model of Cusk; Process, Obs, CPUE and Obs, RV are the process error and observation error on the two biomass indices, P1970 and P2010 are biomass / K for the indicated years. Units for MSY and BMSY are tonnes.

	0.0%	25.0%	Median	75.0%	100.0%
r	0.000044	0.043755	0.089435	0.153875	0.674700
K	20394	52052	68872	90219	474492
Q, CPUE	0.000005	0.000029	0.000042	0.000062	0.000229
Q, RV	0.0162	0.1333	0.1990	0.3011	1.9790
Shape	1.1930	1.8650	2.1090	2.4230	4.6960
Process	0.0056	0.0760	0.1200	0.1637	0.3864
Obs, CPUE	0.1591	0.2715	0.3042	0.3418	0.5821
Obs, RV	0.0628	0.5061	0.5666	0.6305	1.0300
P1970	0.42	0.89	0.97	1.03	1.76
P2010	0.04	0.10	0.14	0.20	0.82
MSY	1	924	1575	2180	12000
BMSY	10190	26058	34395	45253	236300

These results are very similar to those of Davies and Jonsen (2011) recognizing the uncertainty in the parameters. The intrinsic rate of population growth, r, is 0.09, close to the previous estimate of 0.12. The carrying capacity, K, is slightly higher at almost 69 kt compared to the previous estimate of 52 kt. MSY and B_{MSY} are estimated to be 1.6 kt and 34 kt respectively, compared to the previous estimates of 1.5 kt and 26 kt. Most significantly, the shape parameter on the DFO summer survey is well above one, with the median estimate being 2.1 (the previous estimate was 2.5). This is strong support for the hyperdepletion hypothesis.

Davies and Jonsen (2011) indicated that there is high uncertainty in the parameter estimates of the model. For instance, biomass is estimated to be close to virgin levels in 1970. However, Cusk have been fished since the early 1900s. Canadian reported landings in the 1960s averaged about 4000t annually. Thus, it is highly unlikely that the stock was at carrying capacity. More credence should be given to the model's relative rather than absolute trends in biomass. Given the parameter uncertainties, Davies and Jonsen (2011) showed that the model could not be used to reliably predict future states under different catch scenarios. While an annual catch of 750 t (close to recent values) should be sufficient to allow biomass increase, this in fact has not occurred. Davies and Jonsen (2011) consider that this could be due to 1) high bycatch mortality, 2) lack of data on recent recruitment, 3) poor recruitment during 2000 – 2007 or 4) reduced productivity / increased natural mortality. While the model can explain historical trends, it does not appear to be informative in the prediction of future states. Given this uncertainty, it was decided not to undertake analyses of recovery trajectories.

Fluctuations and Trends

The overall trend in most indices of mature abundance and biomass are of long term decline. The times series of Cusk abundance from the DFO summer survey adjusted for hyperdepletion, commercial longline CPUE, and Halibut longline survey, standardized to their 2000 – 2010 means, are provided in Figure 32. The DFO summer survey indicates a continuous decline since the mid-1970s to the present. The commercial CPUE index has declined continuously since it began in 1986 and at a rate comparable to the adjusted DFO trawl survey index. The Halibut survey time series is too short to indicate long-term changes. However, it has been stable since it began in 1999.

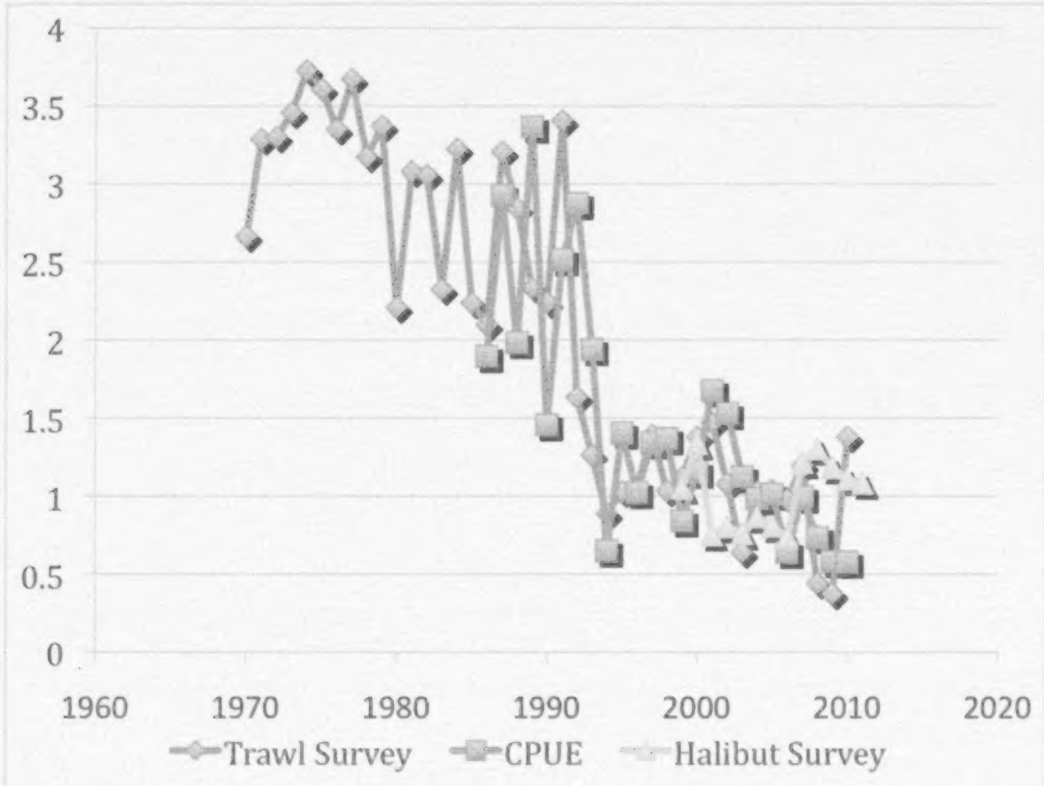

Figure 32. Cusk abundance indices from the DFO trawl survey adjusted for hyperdepletion, the commercial longline CPUE, and the Halibut longline survey, standardized to their 2000 – 2010 means.

The annual instantaneous rate of change (α) in the various indices were determined as the slope of the ln(index) versus year (log-linear regression). Data on the number of mature individuals were available for the DFO trawl surveys, and for mature biomass for the commercial CPUE and Halibut survey indices.

The percent change (%Δ) over a specific time period t was estimated using equation 5. The regressions are plotted in Figure 33.

$$\%\Delta = 100 * (\exp(\alpha * t) - 1) \qquad (5)$$

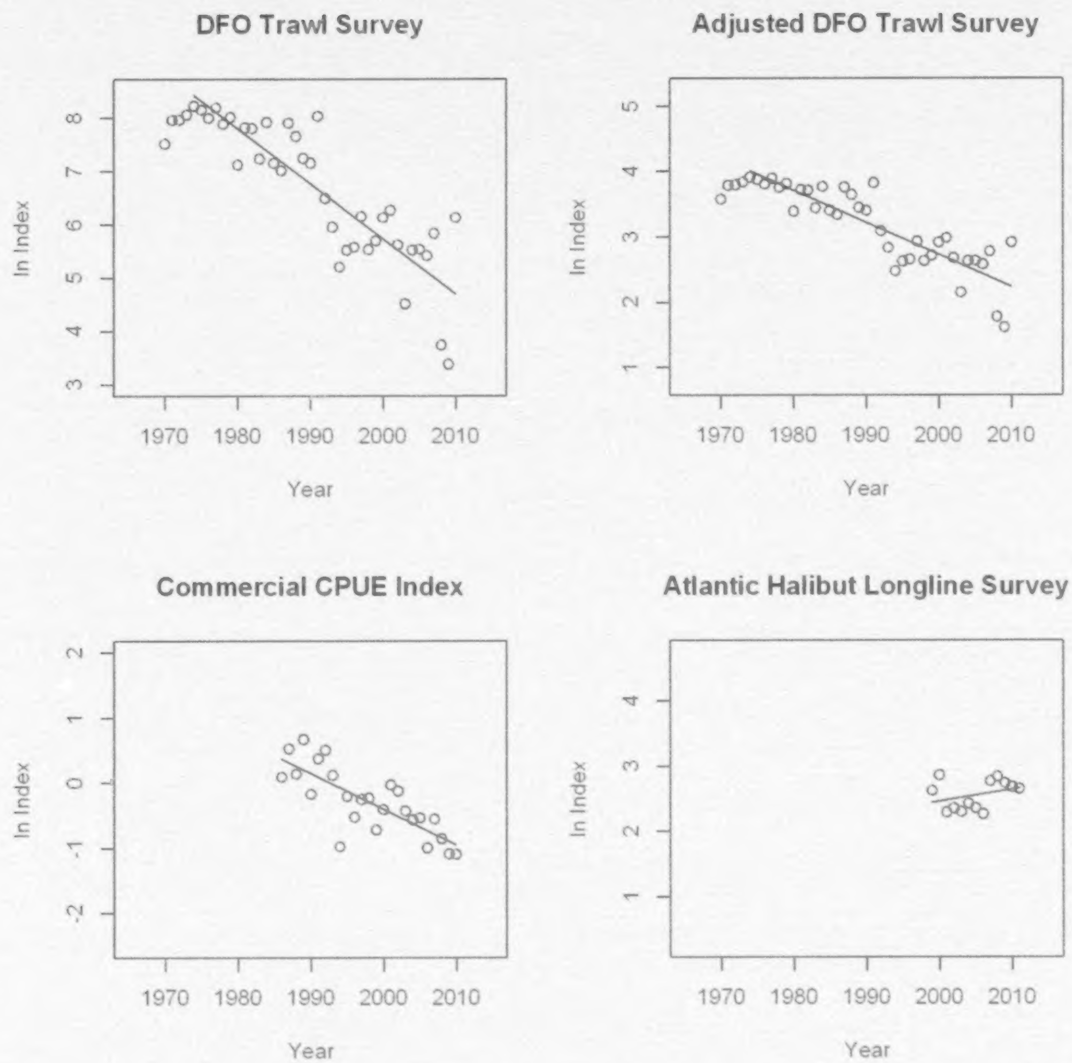

Figure 33. Log linear regressions of Cusk abundance from the DFO trawl survey index (1974-2010), the same index adjusted for hyperdepletion, the commercial CPUE index (1986-2010) and the Halibut longline survey (1999-2011). The range of the y-axis values in each panel is the same thus allowing visual comparison of the estimate slopes.

The estimated change in mature population numbers from the DFO summer survey over a 3-generation period (1974-2010) was -98%, based on a statistically significant slope estimate of -0.103 (Table 13). A regression over the last 2-generations (1986-2010) produced a statistically significant slope estimate of -0.117 which gives an estimated change over this time period of -94%. The slope estimate from the latest one-generation time period (1998-2010) was not significant but the estimated change was -70%. For the CPUE time series, the slope estimate for the last 2 generations (1986-2010) was statistically significant and indicated a change of -73%. The estimated change over the last generation was -55%, based on a significant slope estimate of -0.067. The regression of the Halibut survey results produced a positive but non-significant slope estimate of 0.018, and this indicates a change of +24% over the time period. The results from the NMFS fall survey indicate a change in mature numbers of -83% over the latest 3 generations.

Table 13. Summary of log-linear regression results for the various abundance indices for Cusk. Slope estimates are presented for three time periods (12, 24 and 36 years). The final column gives the estimated percent change in abundance for each time period.

Source	Years	Time Period (years)	N	Slope	SE	P-val	% Change over Time Period
DFO Summer Survey	1974-2010	36	37	-0.103	0.010	<0.0001	-98%
	1986-2010	24	25	-0.117	0.021	<0.0001	-94%
	1998-2010	12	13	-0.100	0.063	0.141	-70%
DFO Summer Survey Adjusted for Hyperdepletion	1974-2010	36	37	-0.049	0.005	<0.0001	-83%
	1986-2010	24	25	-0.056	0.010	<0.0001	-74%
	1998-2010	12	13	-0.048	0.030	0.141	-43%
CPUE	1986-2010	24	25	-0.055	0.009	<0.0001	-73%
	1998-2010	12	13	-0.067	0.018	0.0034	-55%
Halibut Survey	1999-2011	12	13	0.018	0.016	0.294	24%
NMFS Survey	1974-2010	36	37	-0.049	0.011	<0.0001	-83%
Surplus Production Model	1974-2010	36	37	-0.053	0.001	<0.0001	-85%

The surplus production model results indicate that biomass was close to virgin levels in 1970 and declined to 14% of this by 2010. This is an 85% (equation 5 applied to proportion data of Figure 31) decline in biomass over 3 generations (Figure 34). The estimated shape parameter β was used to adjust the DFO survey results using the equation $\hat{I}_t \approx I_t^{1/\beta}$ and a log-linear regression of the adjusted index produced an estimated 3-generation decline of 83%, and a decline of 73% over the past 2 generations, the same time period covered by the CPUE index. In other words, the trends in the adjusted DFO survey and CPUE index are similar.

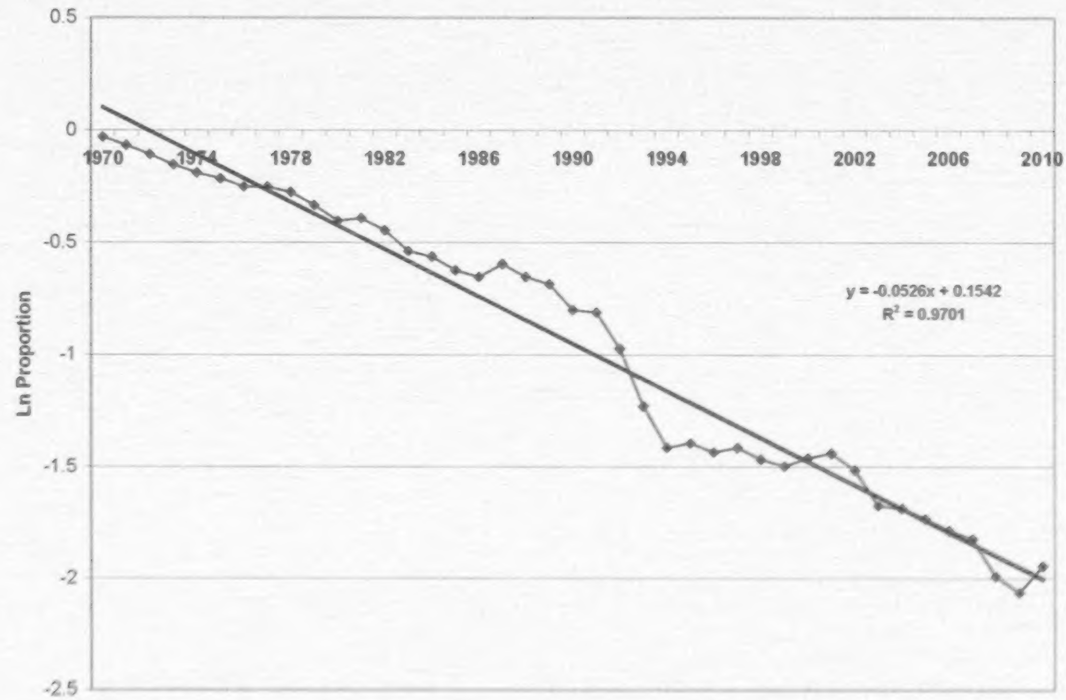

Figure 34. Trend in Ln Proportion annual biomass of carrying capacity from Bayesian Surplus Production Model.

The overall estimated decline of 85% is more extreme than the 63% estimated by Davies and Jonsen (2011). It should be noted that some of this difference is related to how the percent decline is estimated. As noted above, Davies and Jonsen (2011) estimate a 59% decline in Cusk biomass between 1970 and 2001 and a 64% decline from 1970 to 2007. The latter is based upon the ratio of the 1970 to 2007 proportion biomass (of carrying capacity) or 1 - 0.34/0.91 = 63%. The estimate based upon equation 5 is 75%. To further explore the source of the change in perception between Davies and Jonsen (2011) and this assessment, the original model was run using updates to the 1970 – 2007 catch, CPUE and DFO summer trawl survey data both separately and combined. The updates produce similar percent declines in biomass during 1970 – 2007 to those of Davies and Jonsen (2011), suggesting that it is the addition of the 2008 – 2011 data that is causing the perception of further decline (Table 14).

Table 14. Percent decline in proportion biomass of carrying capacity during 1970 – 2007 under different catch, CPUE and DFO summer survey updates to Bayesian surplus production model of Davies and Jonsen (2011).

Model	Percent Decline over 3 Generations	R2
Davies & Jonsen (2011) data	75.2%	0.86
1970 – 2006 catch updated	78.9%	0.88
1970 – 2007 CPUE updated	73.2%	0.87
1970 – 2007 DFO summer survey updated	78.2%	0.89
1970 – 2007 catch, CPUE and survey updated	76.9%	0.89

A trend that the model does not capture is the stability (or slight increase) in mature biomass since 1999 reflected in the Atlantic Halibut survey (Figure 24). The slope of the Halibut survey is not significantly different from zero, whereas those of the other indices (except for the 1998 – 2010 DFO Summer Survey), are significantly different from zero (Table 13). The model indicates a continuing decline during this period. Davies and Jonsen (2011) did not include this index in their model, as was done here, due to the shortness of the time series.

The following is a summary of the main conclusions of the trend analyses. The DFO summer bottom trawl survey indicates a long-term decline in abundance and biomass, even when hyperdepletion is taken into account. Associated with this decline has been a shift to smaller sizes and a reduction in the IAO. The longline CPUE has also declined at a similar rate and there has been a shift in the catch's size composition to smaller individuals. Of note is that the fishery and survey occur in generally the same area, so that this correspondence in trends indicates that they are measuring the same process. The population model also indicates a continuous decline in Cusk biomass over the past 3 generations. The Halibut survey indicates that large Cusk are still present on the Scotian Shelf and that biomass has been stable since 1999. The Halibut survey samples deeper waters off the Shelf that are outside the coverage of the trawl survey. It is possible that these waters still contain large Cusk, whereas they have been depleted on the Shelf proper.

Rescue Effect

The main source of a rescue effect for Cusk in Canadian waters would be from Cusk in the Gulf of Maine in US waters. As indicated in the population trends above, Cusk in this region have declined to a similar extent as in the Canadian zone. Indeed, NMFS conducted a workshop in November 2009 to describe its status from an endangered perspective and many of the issues noted for Canadian Cusk were also mentioned. Thus, this and the low suspected movement rates of Cusk suggest that the likelihood of a rescue from the US Gulf of Maine is low. There is thought to be little movement of Cusk between West Greenland and Canadian waters.

THREATS AND LIMITING FACTORS

Overfishing is the most important threat to Cusk. There are two sources of information on the impact of fishing on the Cusk population. The first is the landings reported by NAFO statistical area on an annual basis and the second is discards in various fisheries as reported by various observer programs. Regarding landings, most Cusk is taken as bycatch in fisheries directed at other species, particularly Cod, Haddock and Pollock. Traditionally, a longline fishery for 'shack' has been recognized, which was directed for Cusk and White Hake combined. 'Shack fishing' (Cusk and White Hake directed fishing combined) accounted for 50% of the Cusk catch prior to 1999 and 33% subsequently (COSEWIC 2003).

The nominal catch[2] of Cusk in the Northwest Atlantic Fisheries Organization (NAFO) Statistical Areas (Figure 35, Table 15) varied between about 3000t and 8000t from 1960, when records began, until the early 1990s, at which time landings fell to less than 2000t. Almost all landings came from the Scotian Shelf – Gulf of Maine area. Small quantities were also caught on the Grand Banks (SA3) and, in the 1960s and 1970s, off West Greenland (SA1). Almost no landings were reported from off Labrador (SA2) or from the Gulf of St. Lawrence – Sydney Bight (4RSTVn).

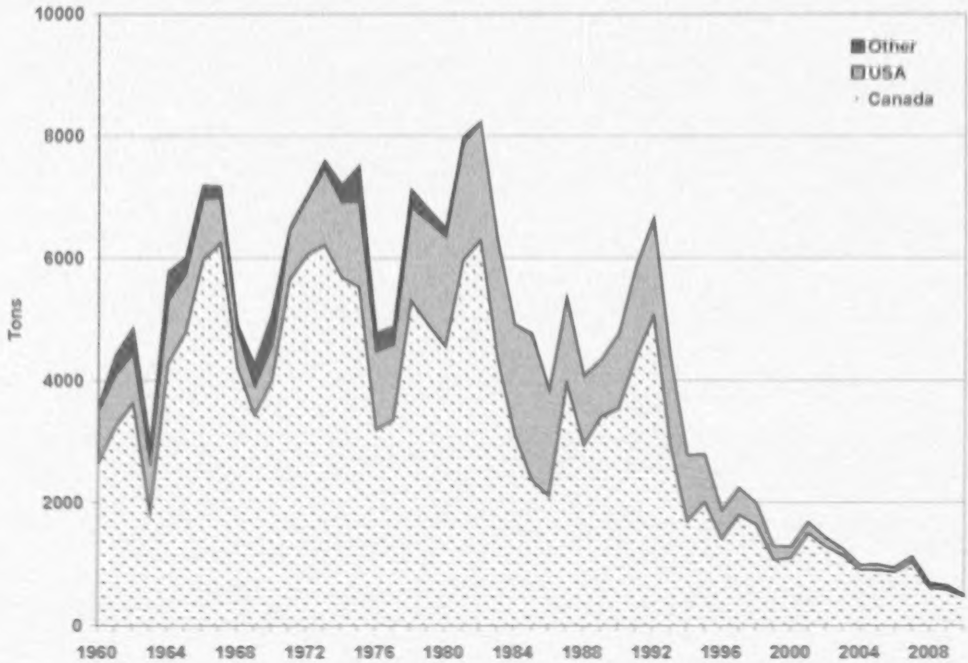

Figure 35. Total annual reported landings of Cusk in the Northwest Atlantic.

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[2] Nominal catch is the estimated live weight of kept catches that are reported as landings in national statistical systems and submitted to NAFO.

Table 15. Reported landings (t) of Cusk for all countries by NAFO Statistical Areas.

	SA1	SA2	SA3	4RSTVn	4VsW	4X	SA 5+6 + NK	Total	Canada	USA
1960	31		32	5	193	2532	768	3561	2643	871
1961	259		88	15	235	3090	726	4413	3247	856
1962	393		15	4	490	3160	793	4855	3625	836
1963	225		24	10	265	1634	782	2940	1828	865
1964	413	4	42	7	263	4098	945	5772	4268	1037
1965	230	4	15	2	688	3945	1112	5996	4778	974
1966	204	1	11	1	644	4352	1973	7186	5973	995
1967	158		20		528	4102	2362	7170	6244	757
1968	61		34		534	2620	1663	4912	4213	606
1969	119	27	208		359	2376	1168	4257	3429	479
1970	5	7	487	5	393	2822	1365	5084	3995	600
1971	1		76	13	321	4263	1823	6497	5642	811
1972	4		22	17	299	4999	1685	7026	6053	932
1973	80		59	1	519	5130	1803	7592	6211	1255
1974	57		147	25	627	4606	1731	7193	5683	1236
1975	134	34	321	24	668	4499	1827	7507	5526	1407
1976	136	63	83	1	604	2390	1491	4768	3189	1285
1977	282		15	9	289	2872	1407	4874	3352	1238
1978	258		33	8	457	4459	1907	7122	5307	1537
1979			191	4	438	3975	2186	6794	4908	1696
1980			119	11	249	3676	2434	6489	4551	1807
1981			95	7	422	3529	3928	7981	5965	1924
1982			2	12	690	4538	2987	8229	6290	1937
1983			7	4	536	3322	2439	6308	4364	1941
1984			8	1	249	2471	2185	4914	3126	1788
1985		1	35	1	246	1843	2640	4766	2375	2363
1986			22	5	323	1675	1817	3842	2107	1729
1987	3		42	3	496	3182	1634	5360	3954	1391
1988			12	4	282	2308	1471	4077	2938	1131
1989			9		436	2312	1580	4337	3402	935
1990			16	2	608	2488	1651	4765	3541	1224
1991			9	8	656	3105	2105	5883	4381	1498
1992			20		507	3693	2432	6652	5053	1581
1993			21		312	2043	2009	4385	2945	1431
1994			9	3	292	1213	1260	2777	1693	1084
1995			6	1	289	1534	962	2792	2010	782
1996			3		164	1045	661	1873	1405	468
1997			3		173	1476	591	2243	1800	443
1998			7		186	1306	495	1994	1640	354
1999			9	1	151	788	347	1296	1066	230
2000			6	1	116	785	377	1285	1097	188
2001			9		109	1041	523	1682	1502	180
2002	0		2		102	867	465	1436	1286	150
2003			11		75	750	414	1250	1141	104
2004	1		3	0	67	575	340	986	906	79
2005	1		4	0	47	723	222	997	900	96
2006	9		7	0	30	663	233	942	868	65
2007	0		5		50	838	227	1120	1032	88

	SA1	SA2	SA3	4RSTVn	4VsW	4X	SA 5+6 + NK	Total	Canada	USA
2008	30		6	0	47	509	104	696	612	54
2009	28		4	0	39	453	129	653	576	48
2010			4	0	30	364	105	503	469	34

While US landings were significant in the 1980s, the majority of landings have been reported by Canada, this by vessels operating in DFO's Maritimes Region. The Canadian share of the landings from 1960 to present has been 78% while the US share has been 20%. The remainder is accounted for by various other countries, predominantly fishing in the northern areas (SA1-3).

Canadian landings have predominantly been from the western Scotian Shelf – Bay of Fundy (4X) with Georges Bank (5Z[3]) being second in importance (Table 16). Total Canadian catches were as high as 6000 t in a number of years but have been consistently below 2000 t since 1995. The USA fishery was limited to NAFO Subarea 5 after the international boundary determination in 1984. Prior to that date, less than 5% of USA catches were reported from SA4. Within SA5, about 2/3 of USA catches were reported as being from the Gulf of Maine (5Y) and 1/3 from Georges Bank. Total USA catches were as high as 2000 t in some years but have been less than 500 t since 1995 (Table 17).

Since the 1970s, the Canadian fishery has been dominated by longline vessels (Table 18) operating during the second and third quarter of the year (Figure 36).

Table 16. Canadian landings (t) of Cusk by NAFO Statistical Area.

	SA3	4RST	4Vn	4VS	4W	4X	5Y	5Z	Total
1960	16	5		18	169	2435			2643
1961	37	9	6	9	223	2959		4	3247
1962	14		4	12	473	3097		25	3625
1963	2	9	1	8	248	1517		43	1828
1964		1	6	8	248	3933		72	4268
1965	5	1	1	19	669	3880		203	4778
1966			1	43	600	4281	10	1038	5973
1967	9			31	497	4002	3	1702	6244
1968	2			29	505	2577	8	1092	4213
1969	5			24	335	2339	1	725	3429
1970	10	3	1	15	371	2782	1	812	3995
1971	33	11	1	23	292	4242	8	1032	5642
1972	22	15		28	231	4989		768	6053
1973	13		1	37	474	5105	1	580	6211
1974	23		1	34	522	4588	2	513	5683
1975	28		1	49	526	4473	9	440	5526

[3] Determination of the maritime boundary between Canadian and USA waters in 1984 restricted fishing to domestic waters, 5Zc in the case of Canadian fishermen and 5Zu in the case of USA fishermen. In prior years, fishermen of both countries had access to all of Georges Bank (5Ze), and also to more westerly areas (5Zw+SA6) but there were almost no reports of catches in these more westerly areas by either country.

	SA3	4RST	4Vn	4VS	4W	4X	5Y	5Z	Total
1976	10	1		76	508	2342		252	3189
1977	15	6	3	33	255	2834		206	3352
1978	14	6	2	54	401	4414		416	5307
1979	4	2	2	47	391	3952	1	509	4908
1980	2	8	3	67	181	3627		663	4551
1981	5	5	2	62	360	3460	88	1983	5965
1982	2	9	3	82	607	4425	4	1158	6290
1983	7		4	89	444	3219		601	4364
1984	8		1	68	181	2391		477	3126
1985	33		1	55	167	1821		298	2375
1986	21	1	4	82	235	1639		125	2107
1987	42	1	2	162	322	3165		260	3954
1988	11		4	88	186	2302		347	2938
1989	9			98	338	2307		650	3402
1990	16		2	74	534	2449		466	3541
1991	6		8	107	548	3097		615	4381
1992	20			24	479	3674		856	5053
1993	21			49	262	2035		578	2945
1994	9		3	102	190	1213		176	1693
1995	6		1	69	220	1534		180	2010
1996	3			34	130	1045		193	1405
1997	3			28	145	1476		148	1800
1998	7			32	154	1306		141	1640
1999	9		1	23	128	788		117	1066
2000	6		1	17	99	785		189	1097
2001	9			24	85	1041		343	1502
2002	2			23	79	867		315	1286
2003	6			19	56	750		310	1141
2004	3	0	0	13	54	575		261	906
2005	4	0	0	10	37	723		126	900
2006	7	0		8	22	663		168	868
2007	5			11	39	838		139	1032
2008	6	0	0	15	32	507		52	612
2009	4	0	0	16	23	453	1	79	576
2010	4		0	7	23	364	0	71	469

Table 17. US landings (t) of Cusk by NAFO Statistical Area.

	SA3	4RST	4W	4X	5Y	5Z+NK	SA6+NK	Total
1960			6	97	460	308		871
1961			3	131	486	236		856
1962			5	63	518	250		836
1963			9	117	420	319		865
1964			7	165	471	394		1037
1965				65	378	531		974
1966			1	71	345	578		995
1967				100	236	421		757
1968				43	218	343	2	606
1969				37	201	241		479

	SA3	4RST	4W	4X	5Y	5Z+NK	SA6+NK	Total
1970		1	7	40	363	189		600
1971		1	6	21	532	251		811
1972			6	10	668	248		932
1973			8	25	972	249	1	1255
1974			2	18	977	239		1236
1975			3	26	1052	326		1407
1976			1	47	948	288	1	1285
1977			1	36	889	311	1	1238
1978			1	45	1056	435		1537
1979				20	1035	641		1696
1980				37	1163	605	2	1807
1981				67	1270	584	3	1924
1982				112	1256	569		1937
1983				103	1314	524		1941
1984				80	1129	579		1788
1985				21	1748	594		2363
1986	1			36	1279	413		1729
1987				17	957	417		1391
1988	1			6	688	436		1131
1989				5	599	331		935
1990				39	841	342	2	1224
1991				8	1040	450		1498
1992				5	1023	553		1581
1993					679	752		1431
1994							1084	1084
1995							782	782
1996							468	468
1997							443	443
1998							354	354
1999							230	230
2000							188	188
2001							180	180
2002							150	150
2003								104
2004							79	79
2005							96	96
2006							65	65
2007				0	68	16	4	88
2008				2	36	12	4	54
2009								48
2010								34

Table 18. Canadian Cusk landings (t) in the Northwest Atlantic by gear.

	Otter Trawl	Line	Gillnet	Trap	Other	Total
1960	717	1514	2	0	410	2643
1961	1082	1837	48	0	280	3247
1962	1626	1922	4	0	73	3625
1963	1182	562	12	0	72	1828
1964	1648	537	0	0	2083	4268
1965	372	3865	0	0	541	4778
1966	383	5041	16	0	533	5973
1967	526	5464	32	0	222	6244
1968	351	3751	9	0	102	4213
1969	381	2839	42	0	167	3429
1970	177	3659	4	5	150	3995
1971	315	5196	15	4	112	5642
1972	250	5634	9	42	114	6049
1973	215	5819	2	6	169	6211
1974	105	5436	11	65	55	5672
1975	171	5095	41	138	69	5514
1976	109	3002	45	18	14	3188
1977	86	3066	64	58	77	3351
1978	205	4895	142	13	52	5307
1979	134	4714	41	3	16	4908
1980	153	4212	93	53	40	4551
1981	121	5710	64	36	30	5961
1982	54	6139	50	46	1	6290
1983	40	4212	83	28	1	4364
1984	29	3069	21	7	0	3126
1985	31	2211	26	107	0	2375
1986	29	1758	46	273	0	2106
1987	88	3699	112	50	2	3951
1988	76	2810	32	17	3	2938
1989	36	3232	71	61	2	3402
1990	34	3355	82	70	0	3541
1991	27	4217	31	54	1	4330
1992	16	4827	86	116	0	5045
1993	35	2789	56	41	0	2921
1994	43	1572	48	29	0	1692
1995	34	1928	19	29	0	2010
1996	8	1341	23	15	0	1387
1997	17	1742	21	20	0	1800
1998	49	1550	13	2	0	1614
1999	22	1035	8	0	1	1066
2000	17	1049	9	0	0	1075
2001	27	1466	9	0	0	1502
2002	26	1228	0	0	0	1254
2003	31	1098	0	0	0	1130
2004	23	876	5	0	2	906
2005	20	875	5	0	0	900
2006	19	846	3	0	0	868
2007	11	1016	5	0	0	1032

	Otter Trawl	Line	Gillnet	Trap	Other	Total
2008	16	588	5	0	0	610
2009	27	542	6	0	0	575
2010	12	378	7	0	0	398

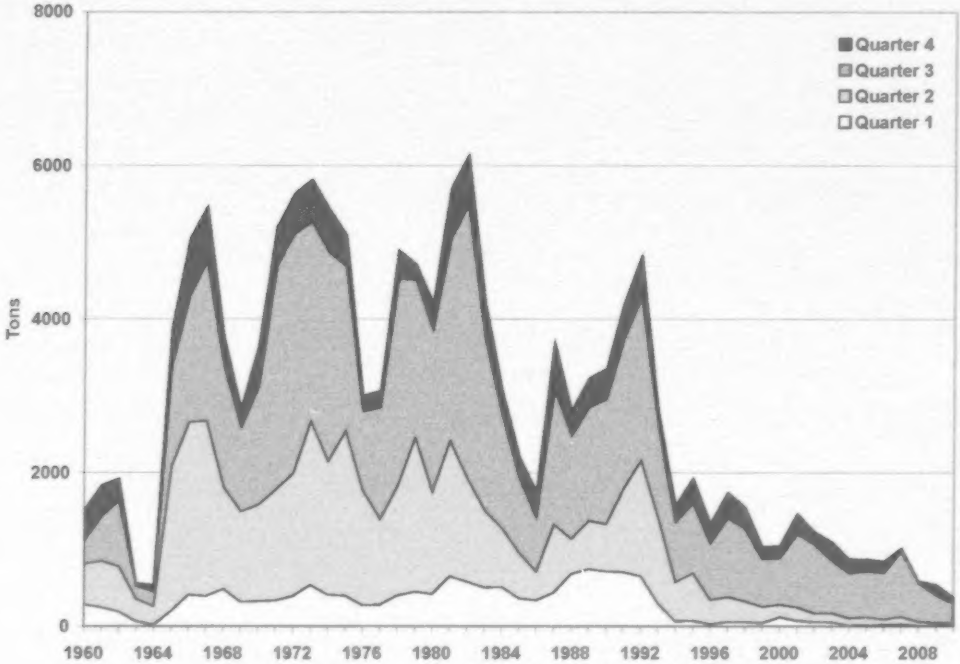

Figure 36. Longline landings of Cusk by quarter of the year.

Regarding the second source of mortality (discards), there are no data available from ongoing monitoring of the fishery. There are, however, recent studies which allow estimation of Cusk discard rates. Regarding post-capture mortality (PCM), Harris and Hanke (2010) estimated that in the Lobster fishery in lobster fishing area (LFA) 34 and 41, 49% and 86% of captured Cusk were dead. This is likely an underestimate of PCM because discarded Cusk do not survive given the propensity for the stomach to evert during gear retrieval (Harris and Hanke 2010). It is assumed here that post-capture mortality is 100%.

Gavaris *et al.* (2010) undertook a comprehensive analysis of the 2002 – 2006 observer information for NAFO Divs. 4V to 5Z. While noting that observer coverage was generally too low to provide reliable estimates of discard rates, they give an indication of which fisheries are most likely discarding Cusk, these being longline, trawl and lobster trap. Discard rates in longline and trawl fisheries operating in NAFO Divs 4VW – 5Z were generally small (Table 19), averaging less than one percent. Thus, discards were not computed for these fisheries. However, the discard rates in the lobster trap fishery were 2 – 5% and this could be significant given the large amount of lobster gear fishing off Southwest Nova Scotia.

Table 19. Cusk discard rates (kg Cusk discarded per kg of all species landed; courtesy of K. Clark) (from study by Gavaris *et al.* 2010).

		Discard Rate (Discards, kg/All Species Landings, kg)					
Area	**Fishery**	**2002**	**2003**	**2004**	**2005**	**2006**	**Average**
4VW		0	0.000125	0	0.004422	0	0.09%
4X5Y	Longline	0	0.000093	0	0	0	0.00%
5Z		0	0.004066	0.002423	0	0.000009	0.13%
4VW		0	0	0	0	0	0.00%
4X5Y	Trawl	0	0	0.000255	0.000012	0	0.01%
5Z		0.000002	0.000035	0	0	0.000002	0.00%
4VW		0					0.00%
4X5Y	Lobster trap	0.012911	0.015330	0.035383	0.024078	0.014946	2.05%
5Z		0.021611	0.033683	0	0.110275	0.052599	4.36%

Two subsequent studies have been undertaken focused on the lobster fishery operating in Southwest Nova Scotia. The first was conducted during 2005 – 07 with sampling focused in LFA 34 and some undertaken in LFA 41. The design and results of this study are available in Harris and Hanke (2010).

The second study was conducted during 2009 – 10 with sampling effort again focused on the lobster fishery off Southwest Nova Scotia. The results of this study were peer reviewed at a DFO Science meeting in August 2010 but have not yet been published. The findings reported here are preliminary and were provided by Pezzack (2011), who noted that no samples were available for LFA 35 – 38 and no Cusk were observed in LFA 27 – 32. A comparison of the 2005-06 and 2009-10 studies is provided in *Table 20 and a comparison of the bycatch rates in the lobster fishery as determined by Gavaris *et al.* (2010), the 2005-07 and 2009-10 studies are provided in *Table 21. For LFAs 33 - 34, in the order of 200 – 400 t of Cusk were estimated to have been discarded while for LFA 41, the discards were estimated in the order of 22 – 25 t. Pezzack (2011) estimated that almost 3 Cusk (13 kg) are discarded for every ton of lobster caught in LFA 33 and 34 respectively. Discards are higher in LFA 41, being about 37 kg of Cusk discarded for every ton of lobster caught. These are very low rates of discards.

*Please note: Table 20 and Table 21 do not appear in this report as they were still considered DRAFT on publishing date. Please contact the Secretariat at: cosewic/cosepac@ec.gc.ca for a copy of final tables.

***Table 20. Comparison of 2005-06 and 2009-10 Cusk bycatch studies (from Pezzack 2011).**

***Table 21. Comparison of Cusk discards in Southwest Nova Scotia Lobster fishery determined by Gavaris *et al.* (2010), the 2005-07 study of Harris and Hanke (2010) and the 2009-10 study of Pezzack (from Pezzack 2011).**

*Please note: Table 20 and Table 21 do not appear in this report as they were still considered DRAFT on publishing date. Please contact the Secretariat at: cosewic/cosepac@ec.gc.ca for a copy of final tables.

Lobster landings in LFAs 33, 34 and 41 since the 1999-2000 fishing season have been in the order of 20,000 t annually. The discard rates noted above imply that Cusk discards in the order of 250 – 300 t per year have been occurring since 1999-2000 (Table 22). This compares to average Canadian reported landings of 500 – 1500 t during this period (Table 16). While Cusk discard rates in the lobster fishery are very low and also highly uncertain, discarding in the Lobster fishery is likely a significant proportion of the recent total catch of Cusk.

Table 22. Cusk discards (t) in Southwest Nova Scotia Lobster fishery estimated based upon recent DFO discard studies.

	LFA33		LFA34		LFA 41		
SEASON	Landings	Discards	Landings	Discards	Landings	Discards	Total Discards
1960-61	1329	4	2305	30	0	0	34
1961-62	1082	3	2548	33	0	0	36
1962-63	1085	3	2896	38	0	0	41
1963-64	1023	3	3221	42	0	0	45
1964-65	960	3	2851	37	0	0	40
1965-66	711	2	2708	35	0	0	37
1966-67	549	2	2710	35	0	0	37
1967-68	803	2	2844	37	0	0	39
1968-69	1056	3	3888	51	0	0	54
1969-70	836	3	4580	60	0	0	62
1970-71	986	3	4066	53	100	4	60
1971-72	616	2	4037	52	334	12	67
1972-73	485	1	4457	58	493	18	78
1973-74	595	2	3771	49	416	15	66
1974-75	531	2	3973	52	545	20	73
1975-76	382	1	3914	51	678	25	77
1976-77	352	1	3463	45	635	23	70
1977-78	213	1	2813	37	684	25	63
1978-79	416	1	3037	39	609	23	63
1979-80	248	1	3229	42	549	20	63
1980-81	363	1	3060	40	573	21	62
1981-82	448	1	3663	48	468	17	66
1982-83	461	1	4546	59	478	18	78
1983-84	1044	3	5138	67	440	16	86
1984-85	1658	5	5938	77	778	29	111
1985-86	2385	7	6891	90	807	30	127
1986-87	2794	8	7673	100	607	22	131
1987-88	2589	8	8479	110	527	19	137
1988-89	1888	6	8201	107	451	17	129
1989-90	2037	6	9449	123	565	21	150
1990-91	2420	7	11071	144	664	25	176
1991-92	1849	6	8876	115	586	22	143
1992-93	1731	5	8916	116	657	24	145
1993-94	1968	6	10326	134	777	29	169
1994-95	1395	4	9692	126	677	25	155
1995-96	1825	5	10307	134	650	24	164

	LFA33		LFA34		LFA 41		
SEASON	Landings	Discards	Landings	Discards	Landings	Discards	Total Discards
1996-97	1867	6	10593	138	678	25	168
1997-98	2104	6	11886	155	538	20	181
1998-99	2162	6	12993	169	729	27	202
1999-00	2297	7	13514	176	711	26	209
2000-01	2521	8	16503	215	717	27	249
2001-02	2753	8	19054	248	726	27	283
2002-03	2344	7	17613	229	718	27	263
2003-04	2006	6	17801	231	717	27	264
2004-05	2524	8	17250	224	1,013	37	269
2005-06	2596	8	16991	221	780	29	258
2006-07	3040	9	16796	218	691	26	253
2007-08	2574	8	16641	216	692	26	250
2008-09	3478	10	17733	231	541	20	261
2009-10	3429	10	19620	255	869	32	298

PROTECTION, STATUS, AND RANKS

Legal Protection and Status

Regarding international acts and legislation, Cusk are not in any of the appendices of CITES.

In Canada, under the *Fisheries Act*, DFO (2011) describes the Conservation Harvesting Plan (CHP) for the fixed gear vessels based in NAFO Div. 4VWX. Other fleets (e.g. mobile gear, offshore) have their own CHP. Also, there is a separate CHP for NAFO Div. 5Z. Cusk landings are controlled through a system of fleet 'caps' for vessels < 45'. The first cap of 1000t was introduced in 1999 which was reduced to 750 t in 2003. This system recognizes the bycatch nature of Cusk with directed fishing for Cusk being prohibited but catch permitted when directing for other groundfish species such as Cod, Haddock, White Hake and so on. Once a cap is reached, Cusk are not allowed to be landed and must be discarded. As noted earlier, PCM is thought to be 100% and it is unlikely that this management measure protects Cusk. Neither the offshore (>100') nor midshore (65'-100') fleets have caps in place as a condition of license. Instead, they are limited to 10% weight by trip and DFO monitors landings to ensure that these do not exceed historical levels. If they do, a cap would be put in place (Docherty 2011). In 2010/11, quota caps for the DFO Maritimes fleets totalled 656 t.

On a trip by trip basis, in NAFO div. 4VWX, Cusk landings are not to exceed 25% of the round weight of the directed species and the trips' landings should not exceed 4,000 lbs (1818 kg) round at any time. In NAFO Div. 5Z, the amount of Cusk on any trip for fixed gear (FG) vessels cannot exceed the lesser of 15% of the amount of Cod, Haddock and Pollock combined onboard the vessel or 3000 pounds (1364 kg) round weight. Further, any individual licence holder found to be deliberately or consistently exceeding this limit is required to have additional observer coverage at their expense. DFO also maintains the option to close the fleet's fishery if this occurs.

FG vessels > 45' are subject to 100 % dockside monitoring (DMP) of landings. The <45' FG vessels are subject to a minimum of 25% DMP and the actual level is closer to 50% (Docherty 2011).

Fixed gear is regulated to a minimum hook gap of 12 mm, which equates to between a 10/0 and 12/0 circle hook (Halliday 2002).

There are no special time / area closures for Cusk except those that have been put in place for other groundfish (e.g. Cod and Haddock) and Lobster. These include the Haddock closures on Brown's and Emerald Bank as well as the LFA 40 Lobster closure. The Brown's and Emerald closures restrict groundfishing, but not Lobster fishing which, as noted above, could be a significant source of Cusk catch. Since 1999, Cusk are not allowed to be landed by Lobster licensed vessels, and they are required to discard all of their catch.

Regarding the *Species at Risk Act*, there are no special provisions for Cusk. COSEWIC assessed Cusk as Threatened in 2003. The Governor in Council elected not to list Cusk under SARA based on a recommendation by the Minister of Fisheries and Oceans. The following summary of the rationale not to list the species was taken from the Canada Gazette dated July 7, 2012.

"In light of the new management measures implemented, the lack of scientific certainty regarding the decline of the species, the potentially higher probability of an increase in Cusk biomass, the socio-economic impacts and stakeholder concerns discussed above, Fisheries and Oceans Canada has proposed not to list the species under SARA and to continue to manage Cusk under the Groundfish Integrated Fisheries Management Plan."

The species is listed as S3S4 in Québec.

In the US, there are no special provisions to protect Cusk under the *Endangered Species Act*. All regulations pertain to the Magnuson – Stevens Fishery Conservation and Management Act (MSRA). There are no TAC or catch limits. Because it is a bycatch to other regulated species, there are no specific gear and time / area regulations other than those that might apply (e.g. closed areas) to directed species fisheries (e.g. otter trawl fisheries in Gulf of Maine or on Georges Bank).

Non-Legal Status and Ranks

Cusk is not listed in the Red List of the IUCN.

Habitat Protection and Ownership

A number of fishery and conservation closures are in place that could potentially protect Cusk habitat (O'Boyle 2011). These include:

- Groundfish Closures, US Gulf of Maine Area (17,131 sq km)
- Haddock Spawning Closure, Browns Bank (12,332 sq km)
- Haddock Nursery Closure, Emerald/Western Bank (12,776 sq km)
- Lobster Closure, Browns Bank (6,554 sq km)
- Gully MPA, Scotian Shelf (2,364 sq km)
- Coral Conservation Areas, Scotian Shelf (439 sq km)

The Haddock spawning closure on Browns Bank prohibits benthic fishing for all groundfishing during March – June but allows fishing during the rest of the year. The Haddock nursery closure on Emerald – Western Bank prohibits benthic fishing for all groundfishing throughout the year but is an area where Cusk are not common. In the US, the year-round fishery closures apply to all groundfishing. However, these closures are not in areas where Cusk are common.

The Gully Marine Protected Area (MPA) is a comprehensive tool under Canada's *Oceans Act* to limit the impacts, benthic or otherwise, of all fishing on the ecosystem. Again, it would have limited benefits for Cusk. Finally, there are two Coral Conservation Areas (CCA) on the Scotian Shelf, the Northeast Channel CCA and the Lophelia CCA. While the latter is expected to have limited benefit for Cusk, this is not the case for the former. All mobile gear groundfishing is prohibited from the area and while longlining is allowed, it is restricted to certain zones and fishing is only allowed with an observer.

Overall, there are a number of regulatory measures in both Canada and the US which, while not specifically targeting Cusk, will likely have some benefit to the protection of the species.

ACKNOWLEDGEMENTS AND AUTHORITIES CONTACTED

The status report writer thanks the following who were contacted, assisted and contributed information and data for this report:

Atlantic Reference Centre, St. Andrew's, NB

L. Van Guelpen

COSEWIC

M. Goit, J. Wu

0BDalhousie University, Halifax, NS

T. Davies, I. Jonsen

DFO Newfoundland Region, St. John's, Nfld

B. Davis, M. Koen-Alonso, B. McCallum, D. Power, A. Russell

DFO Maritimes Region, Dartmouth, NS and St. Andrew's, NB

C. Annand, J. Black, A. Bundy, J. Choi, D. Clark, K. Clark, R. Claytor, D. Bowen, S. Campana, P. Comeau, A. Cook, C. Den Heyer, V. Docherty, R. Halliday, L. Harris, J. Gale, R. Grandy, E. Kenchington, V. Kostylev, T. McIntyre, J. Neilson, G. Parsons, D. Pezzack, J. Porter, A. Serdynska, J. Simon, S. Smith, K. Smedbol, J. Tremblay, T. Worcester

DFO Gulf Region, Moncton, NB

G. Chouinard, R. Morin, D. Swain

DFO Quebec Region, Mont Joli, Que

D. Bernier, H. Bourdages, D. Duplisea, D. Gascon

DFO Central and Arctic Region, Winnipeg, Man

K. Martin, M. Treble

Institute of Marine Research, Bergen, Norway

O. Bergstad, K. Helle

North East Fisheries Science Center, NMFS, Woods Hole, MA

L. O'Brien, P. Rago

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BIOGRAPHICAL SUMMARY OF REPORT WRITER

Mr. O'Boyle received his B Sc. and M Sc. from McGill and Guelph universities in 1972 and 1975 respectively. He joined Canada's Department of Fisheries and Oceans (DFO) at the Bedford Institute of Oceanography (BIO) in Dartmouth, Nova Scotia in 1977 as a stock assessment scientist and was with DFO for over 30 years, retiring in October 2007. During his first 10 years at DFO, he was heavily involved in the development of stock assessment approaches and conducted assessments of most of the Maritime region's fish resources (herring, capelin, cod, haddock, pollock, the flatfishes, and more recently, the large pelagic sharks). He started his career in science program management about this time, heading up the Scotian Shelf Ichthyoplankton Program, the Biomathematics and Computer Section, and the Population Dynamics Section. In 1987, he became a division manager with responsibility for the finfish research programs and assessment-related activities of over 70 scientific and support staff. He remained in this position until 1996, at which time he became responsible for the peer review of the science and advice on the Maritimes Region's finfish, invertebrate and marine mammal resources, on its habitat management, and on its ocean management practices and approaches. He became the Associate Director of Science in 2000, a position that he held until his retirement in 2007, and as such was heavily involved in DFO science program management at the regional and national level. He has been involved in a number of national and international reviews, ranging from science program design to resource assessment. He is president of Beta Scientific Consulting Inc, which provides a variety of services on ocean management including meeting / workshop organization and facilitation, technical analyses, reviews, and outreach. He is also an emeritus scientist with BIO, pursuing research projects related to resource and ocean management and assessment.